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SCHOOL SERIES,

EDITED BY THE
REV. G. R. GLEIG, M.A.
INSPECTOR-GENERAL OF MILITARY SCHOOLS.

MAGNETISM, VOLTAIC ELECTRICITY, AND ELECTRO-DYNAMICS.

FOR THE USE OF BEGINNERS.

BY THOMAS TATE, F.R.A.S.

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1854.

Price One Shilling.

GLEIG'S SCHOOL SERIES.

ON

MAGNETISM, VOLTAIC ELECTRICITY, AND ELECTRO-DYNAMICS.

FOR THE USE OF BEGINNERS.

IN WHICH THE
PRINCIPLES OF THE SCIENCES
ARE FAMILIARLY EXPLAINED
AND ILLUSTRATED BY NUMEROUS EXPERIMENTS AND DIAGRAMS.

BY T. TATE, F.R.A.S.,
LATE MATHEMATICAL PROFESSOR IN THE NATIONAL SOCIETY'S
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MAGNETISM.

THE MAGNETIC POWER.

SUBSTANCES endowed with MAGNETISM attract pieces of iron, and the substances possessing this property are called MAGNETS. Magnetic substances possess various other remarkable properties, which shall hereafter be described. There are two kinds of magnets, — natural magnets and artificial magnets.

Natural Magnets, or loadstones, are iron ores, found at almost every place on the earth. The ancient Greeks were acquainted with the attractive property of the natural magnet, or loadstone; they gave the name of magnet to this mineral, probably because it was found most abundant in the vicinity of Magnesia, a city of Lydia, in Asia Minor.

Artificial Magnets are generally made of steel bars, and the way in which the magnetic property is imparted to them will shortly be described. Artificial magnets are named according to their shape; thus, we have the *bar magnet*, represented in *fig*. 1., and the *horse-shoe magnet*, represented in *fig*. 2. When several bar magnets or horse-shoe

Fig. 1.

Fig. 2.

magnets are combined, the whole is called a *magnetic battery*, or a *compound magnet.*

The magnetic power of a magnetised bar chiefly resides in its extremities, which are called the magnetic poles; one being called the north pole of the magnet, and the other the south pole. In order to distinguish these poles from each other, a mark is usually drawn across the extremity corresponding to the north pole of the magnet.

One of the most remarkable properties of the magnet is, that it communicates its properties to a steel bar or needle that is rubbed for a few times, in the same direction, across one of its poles.

MAGNETIC ATTRACTION.

Experiment 1. Sprinkle some iron filings on a magnetic steel bar; the iron filings will be attracted to the extremities or poles of the magnet, whilst the other portions will be left nearly bare, as shown in *fig.* 3. When the steel bar exceeds eight or ten inches in length, we *sometimes* find two other poles besides those that are at the ends, as shown in *fig.* 4.

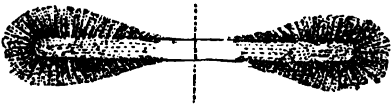


Fig. 3.

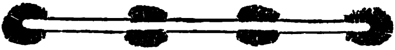


Fig. 4.

Exp. 2. Attract a series of pieces of iron wire, *a*, *b*, *c*, to the extremity N of the magnetic bar N S, as shown in *fig.* 5. Here the wires, while they are in connection with the magnet N S, become a series of little magnets, whose lower extremities are all north poles; that is, of the same name as the pole of the magnet to which they are attached.

Exp. 3. *To magnetise a Pen-knife.*—Rub the knife, for several times, *in the same direction*, that is, from heel to toe, across one of the extremities, or poles, of a magnet; apply the point of the knife to some iron filings, or small pieces of iron,—they will be attracted to the point of the knife.

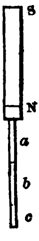


Fig. 5.

The Attraction between a Magnet and Iron is reciprocal.

Whilst the magnet attracts iron, the iron also attracts the magnet.

Exp. 1. Suspend a piece of iron wire by a thread, so that the wire may hang horizontally. Bring the one extremity of a magnet near to one end of the wire; the wire will be attracted by the magnet.

Exp. 2. Suspend a magnetised needle in the same manner; bring the extremity of the iron wire near to either pole of the magnet; the magnet will be attracted by the iron wire.

Magnetic Attraction transmitted through various Bodies.

Exp. 1. Interpose a thin screen of wood, or glass, or copper, or any substance excepting steel and iron, between the magnet and the iron wire of the foregoing experiments; the attraction will take place just as if there were no substance interposed.

Exp. 2. Strew some iron filings on a sheet of white paper; place the pole of a magnet beneath them; the filings will appear to move in whatever direction the magnet is moved.

Exp. 3. Interpose an iron plate between a magnet and an iron wire suspended by a thread; the magnet will have little or no effect upon the wire.

Distribution of Magnetism in a magnetised Bar.

The inequality of this distribution may be readily proved by the following experiments.

Exp. 1. Strew some iron filings on a sheet of white card-paper, beneath which a bar magnet has been placed; occasionally tap the paper to facilitate the arrangement of the filings. The beautiful distribution of the filings (as exhibited in *fig.* 6.)

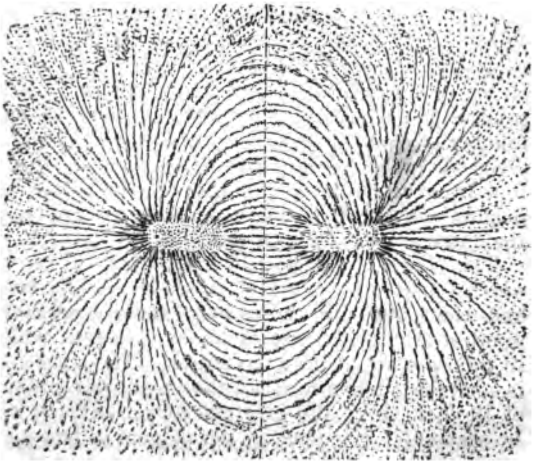


Fig. 6.

around the bar, shows the manner in which the attractive force of the different points in the bar vary, — the filings are most accumulated round the two poles, towards which they seem to converge from all parts, as to the principal centres of action: on the other hand, the central portion of the bar scarcely attracts any of the iron filings, thereby showing that the centre of the bar is a neutral point; that is to say, it does not possess any attractive power. The curves formed by the filings are known by the name of the magnetic curves.

This experiment furnishes us with a ready method of detecting the poles of a natural magnet.

Exp. 2. Take a magnetic bar, N S, *fig.* 7., and support it at its middle point C; apply at any number of equidistant points, *a*, *b*, *c*, *c′*, *b′*, &c., a series of pieces of soft iron wire; then it will be found that the number of pieces of wire which the magnet can support will increase as we approach the extremities or poles N and S.

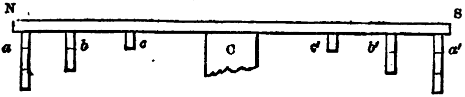


Fig. 7.

The centre, C, of the bar has been called the *neutral point*, or *point of magnetic indifference*, and the poles are those two points where the greatest attractive force is found to reside, which in this case are at the extremities. The term pole is sometimes taken to mean that point in each half of the bar where the greatest attractive force will be accumulated, supposing the magnet to be acting upon a piece of iron or steel placed at a little distance from it; in this case the poles are, on an average, at the distance of about one-tenth of an inch from each extremity.

MAGNETIC POLARITY.

DIRECTIVE PROPERTY OF THE MAGNETIC NEEDLE.

A MAGNETISED steel needle, suspended horizontally by a thread, or on a fine point, will always point very nearly north and south. This is called the *directive* polarity of the magnet. This direction is so constant, that, when the needle is displaced, it returns exactly to it, after a few vibrations. Moreover, the same extremity of the needle always points to the north, and the same extremity to the south; so that if the needle be turned half-way round, it will not rest until it has resumed its original position. The extremity which points towards the north is called the north pole of the magnet, and that which points towards the south, the south pole of the magnet. This remarkable property has been of great use to navigators.

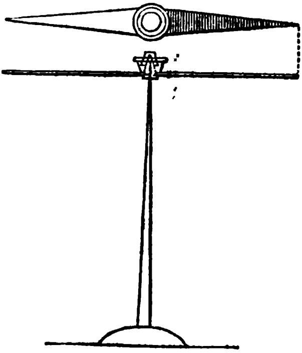


Fig. 8.

Magnetic needles are usually constructed after the form shown in *fig.* 8.; where the needle turns upon a vertical point, which enters the conical cap, screwed into the centre of the needle.

The direction in which the needle points has been called the line of the *magnetic meridian.* This line does not exactly coincide with the direction of the geographical meridian, as we shall hereafter more fully explain. At London, the needle at present points about 24° west of the true north. This is called the magnetic VARIATION, or magnetic DECLINATION. This declination is not the same for all places on the earth, and it is continually changing for all places on the earth.

Exp. 1. Magnetise a small sewing needle; place the needle on some water, so as to make it float: after a little time the needle will settle itself, and will point in the direction of north and south. If the needle be shifted from this position, it will return to the same position again when left to itself. This experiment may also be readily performed in the following manner:—

Exp. 2. Take a strip of card-paper A B; suspend it upon the point S of a pin passed through a cork, place the magnetised needle N S upon one side of the strip of card-paper; restore the balance by placing some small weight, W, upon the opposite side of the card; then the card will turn round until it points north and south, as before described.

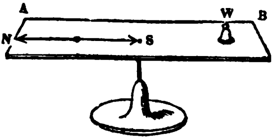


Fig. 9.

With any of these needles the following experiments may be performed (excepting the cases specified).

IRON OR STEEL ATTRACTS BOTH POLES OF THE NEEDLE.

Exp. 3. Hold a bit of iron near either of the poles of the needle; the needle will follow the iron; by moving the iron round, the needle will revolve on its centre in the same direction.

Exp. 4. By holding a bit of iron near to the sewing-needle of *Exp.* 1., it may be made to float about in any direction.

Exp. 5. *The Magnetic Swan.*—This philosophical toy consists of a piece of thin sheet iron, made into the shape of a swan, so as to float upon water.

When the point of a magnet is presented to the swan, it appears to swim towards the point.

THE LIKE POLES OF MAGNETS REPEL ONE ANOTHER, AND THE UNLIKE POLES ATTRACT.

This law of magnetism is exactly analogous to the law of attraction and repulsion of the two kinds of electricity.

In order to distinguish these opposite influences, the magnetic principle of the north pole is called *positive magnetism*, or +, and that of the south pole, *negative magnetism*, or —.

Exp. 6. Bring the north pole of a magnet near to the south pole of the needle, and it will be attracted. Bring the north pole of a magnet near to the north pole of the needle, and it will be repelled; and so on.

This always enables us very readily to ascertain the particular poles of a magnet, or to determine whether or not a metal bar possess magnetism; for the extremity of the bar which attracts the north pole of a needle will be the south pole of the bar, and the other extremity will be the north pole.

Exp. 7. Hang a small key to the north pole of a magnet; present the south pole of another magnet to the upper extremity of the key; the key will instantly fall. Here the two different kinds of magnetism neutralise each other's effects.

Exp. 8. Immerse the like poles of two magnets into some iron-filings; bring the two poles together, and the filings will fall. But if the poles are unlike, the filings will move towards each other.

Exp. 9. Balance a bar-magnet upon a common pair of scales; bring the pole of another magnet immediately beneath one of the poles of the magnet placed on the scale; then, when the poles, thus brought near to each other, are of the same kind, the scale will ascend from the repulsion of the magnets; and, on the contrary, the scale will descend when the poles are of different kinds.

IF A MAGNET BE BROKEN, EACH PART BECOMES A PERFECT MAGNET.

Exp. 10. Break a magnetised knitting-needle; test the polarity of each end of the pieces; the poles of the two magnets will lie in the same direction as the poles of the original magnet.

THEORY OF MAGNETISM.

The theory of magnetism is exactly analogous to the theory of electricity. The magnetic fluid, in its quiescent state, is supposed to consist of two distinct fluids, the one being the NORTH OR POSITIVE MAGNETISM, the other the SOUTH OR NEGATIVE MAGNETISM. When these two fluids are combined, they form the magnetic fluid as it exists in non-magnetised substances, or substances in a neutral state. The particles of the same kind of magnetism repel each other, but the particles of opposite kinds of magnetism attract each other. When the two fluids exist in a body so as to neutralise each other, then the body exhibits no magnetism; but if this se of equilibrium be disturbed by any cause, then the magnetic state is induced. *Fig.* 10. gives a visible representation of this supposed distribution of the particles of the two magnetic fluids in the body of a magnetic bar. Here we suppose the light squares to represent the particles of the positive fluid, and the dark squares the particles of the negative fluid. As the particles of the two fluids are separated from one another, they must arrange themselves according to the law of attraction and repulsion assumed in the theory; that is to say, a positive and a negative particle must always be contiguous to each other: from this it follows, that the extremity N will be a north pole, and S a south pole.

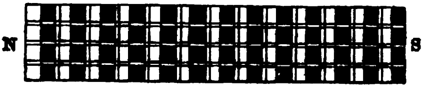


Fig. 10.

This theory readily enables us to explain all the phenomena of magnetism. Let us take a few examples.

1. When the extremity of a bar of soft iron is placed in contact with the north pole of a magnet, the opposite extremity of the bar also exhibits north or positive magnetism; this takes place in consequence of the repulsion of the positive fluid from, and the attraction of the negative fluid to, the north pole of the magnet.

2. When a magnetic needle is broken, it is obvious that the arrangement of the particles of the two fluids must remain unchanged; that is to say, the poles in the two magnets must lie in the same direction as the poles of the original magnet.

3. When the north pole of a magnet attracts a piece of iron wire, the extremity of the wire next to the north or positive pole of the magnet becomes a south or negative pole, owing to the repellant action exerted on the positive fluid, and the attractive action on the negative fluid of the wire, by the positive fluid of the magnetic bar; hence the magnet attracts the wire, according to the law, that bodies magnetised with different fluids attract each other. This also explains the great law of magnetic induction, which we shall shortly consider.

4. The like poles of two magnets repel each other, by virtue of the mutual repulsion subsisting between the particles of the same kind of magnetic fluid; and the unlike poles of two magnets attract each other, in consequence of the mutual attraction subsisting between the particles of the two different kinds of the magnetic fluid.

5. The north pole of the needle is directed towards the north pole of the earth, because the earth itself is a great magnet, having its negative magnetic

pole lying towards its north geographical pole, and its positive magnetic pole lying towards its south geographical pole.

6. The dip of the magnetic needle may be readily explained, by considering the dipping direction of the needle to be the direction of the resultant of the magnetic forces, residing in the earth, which act upon the needle. But this subject will be hereafter more fully explained.

THE ATTRACTIVE FORCE OF MAGNETS DECREASES WITH THE DISTANCE.

Exp. 11. Place the south pole of a magnet at a distance from the north pole of the needle, and a little to the right or left of it; then the needle will be deflected a little from its north and south direction; now bring the magnet a little nearer to the needle, and its deflection will be increased, and so on; thereby showing that the attractive force of the magnet increases as we decrease the distance.

It will also be observed, that the needle vibrates more and more rapidly as the magnetic bar is brought more closely to it. Now the rapidity of these vibrations obviously depends upon the amount of the magnetic force.

The law of the attractive force of a magnet, with respect to distance, is the same as the law of gravitation; that is to say, THE ATTRACTIVE FORCE OF A MAGNET VARIES INVERSELY AS THE SQUARES OF THE DISTANCE.

MAGNETIC INDUCTION AND CONDUCTION.

When a wire of soft iron is placed in contact with the pole of a magnet, it becomes, as it were, a part of the magnet itself; for *every portion* of the wire has the same polarity as the extremity of the magnet with which it is in contact. This may be called magnetic conduction. But if the contact be ever so slightly broken, the wire becomes a complete magnet having two poles, and this takes place in consequence of the operation of another principle, that of induction, which now claims our attention. When the soft iron wire has been entirely removed from the magnet, after a short time it no longer possesses any magnetic properties; it, in fact, was only decidedly magnetic while it was in contact with, or very near to, the magnetised bar. Soft iron receives the magnetic influence most easily, but it also parts with it most easily, when taken away from the magnet. Steel and cast-iron are not so easily magnetised; but when the magnetic property is once imparted to them, they retain it for years, unless they are subject to some counteracting influence.

Magnetic induction is that influence which a magnet exerts upon substances at a distance from it. Let N S be a magnetic bar, N being its north

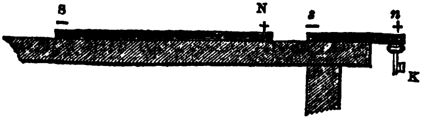


Fig. 11.

pole, and S its south pole; *n s*, a soft iron bar, having its extremity *s* placed near to the extremity N of the magnet; then the soft iron bar *n s* will be a perfect magnet, so long as the pole of the magnet N S is near to its extremity *s*; the extremity *n*, in fact, will be its north pole, and *s* its south pole. To render the magnetic induction apparent, a small key may be suspended from the extremity *n*. The nearer the bar N S is brought to the bar *s n*, the more powerful will be the magnetism induced in it. Let the magnet N S be taken away; then, after a short time, the little key *k* will fall off the bar *s n*, and it will soon lose all traces of magnetism.

Here the positive fluid at N repels the positive fluid from the extremity *s*, and, at the same time, attracts the negative fluid; hence the equilibrium of the two fluids, in the soft iron *n s*, is disturbed, the extremity *s* being in a negative magnetic state, and the extremity *n* in a positive magnetic state; or, in other words, *s* becomes a south magnetic pole, and *n* a north magnetic pole.

Bring the south pole of a bar near to *n*, then the magnetic induction will be doubled; the lower extremity of the little key *k* will rise towards this south pole; and a much heavier key may be supported by the extremity *n*. Now bring the north pole of a bar near to *n*, then the key *k* will instantly drop off; in this case the two poles, being of the same kind, counteract each other's influence.

A series of soft iron bars may be magnetised in the same manner. Thus, let A be a strong magnetic bar; B, C, and D, a series of soft iron bars placed near

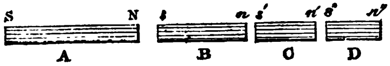


Fig. 12

each other, as shown in *fig.* 12.; then all these soft iron bars, from the action of induction, will become perfect magnets, having their poles as indicated by the letters of the figure.

The law of magnetic induction is exactly analogous to the law of electrical induction.

The following simple experiments will render the law of magnetic induction and conduction more apparent.

MAGNETISM BY CONTACT.

Exp. 1. Place a long piece of soft iron wire in contact with the north pole of a powerful magnet; test the magnetism of the wire by means of a magnetic needle; the south pole of the needle will be every where attracted by the wire, thereby showing that the wire possesses north polar magnetism.

Exp. 2. Cut some short pieces of iron wire; present the end of one of them to the pole of a strong magnet; it will be immediately attracted; the free end of this wire will now attract a second wire, and this in its turn will attract a third wire, and so on. All these wires become little temporary magnets, owing to their connection with the pole of the magnetic bar. In like manner the phenomena of the iron filings adhering to the pole of a magnet may be explained: each filing, thus suspended, is converted into a little magnet.

MAGNETISM BY INDUCTION.

Exp. 1. Place the extremity of a long iron wire opposite to the north pole of a magnetic needle; bring the north pole of a magnetic bar near to the opposite extremity of this wire; the needle will be instantly repelled.

Exp. 2. Suspend two pieces of soft iron by a thread, as shown in *fig.* 13.; bring the north pole of a magnet close to the lower extremities of the wires; the wires will repel each, after the manner shown in the figure.

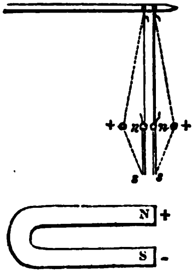


Fig. 13.

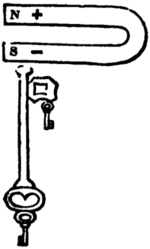


Fig. 14.

Exp. 3. Hold a large key near the pole of a powerful magnet; then, as the key becomes a magnet by induction, it will carry two small keys, one at its lower extremity, and the other at its upper extremity, as shown in *fig.* 14.

THE DIP OF THE MAGNETIC NEEDLE.

Besides the directive property, the magnetic needle, when freely suspended, has another remarkable property called its DIP, whereby its north pole dips towards the north pole of the earth in our hemisphere, and its south pole towards the south pole of the earth in the southern hemisphere.

At present the magnetic dip at London is about 67°.

This property may be readily verified in the following manner.

Experiment. Thrust a knitting needle *n s* through a cork *c*, as shown in *fig.* 15.; at right angles to this needle, thrust a fine sewing needle through the cork which will form the axis of the needle *n s;* attach an untwisted thread *a d b* to the axis, and suspend the whole by the extremity of the thread, taking care to thrust *n s*, either one way or the other, until it is suspended in a perfectly horizontal position. Now magnetise the needle *n s*, which may readily be done by simply keeping it for a short time across the two poles of a horse-shoe magnet. Again suspend the needle, and it will be found that its north pole will dip toward the north. Care must be taken, in magnetising the needle, not to disturb the axis.

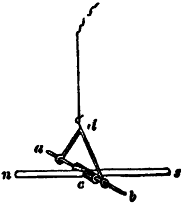


Fig. 15.

This experiment may be performed with more precision by placing the axis *a a* between two upright supports *a b a b*, as shown in *fig.* 16. The best supports for the axis are the edges of two wine-glasses.

The angle which the DIPPING NEEDLE makes with the horizon at any place, is called *the angle of the needle's dip* at that particular place. This angle is not the same for all places. At places in the northern hemisphere the north pole of the needle is depressed, and at places in the southern hemisphere the south pole of the needle is depressed. At places near to the equator the needle has no dip, that is to say, it hangs horizontally.

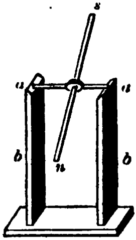


Fig. 16.

Instruments constructed for the purpose of exactly observing the dip, have a vertical graduated circle connected with them, and also a screw adjustment for placing the axis exactly horizontal, as shown in *fig.* 17.

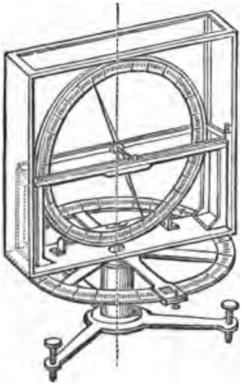


Fig. 17.

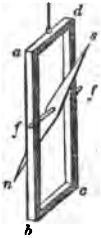


Fig. 18.

Fig. 18. represents a simple form of magnetic apparatus, for showing the direction of the needle as well as its dip. By this contrivance, the needle *n s* has a two-fold free motion, viz., a free motion with respect to its directive property, and a free motion, on its horizontal axis *f f*, with respect to the angle of its dip. *a b c d* is a light frame suspended by an untwisted thread; the horizontal axis *f f* of the needle turns freely in the sides *a b* and *d c* of the frame. A needle, thus suspended, will settle itself in the plane of the magnetic meridian, and will also assume the true angle of the dip.

The subject of magnetic variations, &c., will be more fully explained in connection with that of ial Magnetism.

TO MAGNETISE STEEL BARS, &c.

I. TO MAGNETISE A NEEDLE WITHOUT USING AN ARTIFICIAL MAGNET.

Fix the needle, against the edge of a table, in the magnetic meridian, that is, nearly north and south; hold a long poker above the needle, and another one below it, as shown in *fig.* 19.; then move the pokers in contrary directions until they come to the positions shown in *fig.* 20.; repeat this operations for several times, always observing at every successive operation to move the pokers in the same manner, and the needle will be magnetised. Here the pokers, being held in the direction of the magnetic dip, really become magnets. (See the subject of Terrestrial Magnetism.)

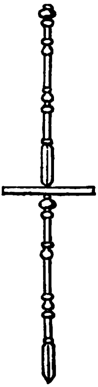


Fig. 19.

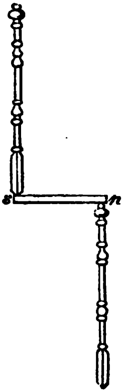


Fig. 20.

II. TO MAGNETISE STEEL BARS, &c., BY MAGNETS.

There have been various processes devised for magnetising steel bars, the following are amongst the most simple and efficient: —

Most easy Methods of magnetising a small Needle.

Exp. 1. Bring the pointed extremity of a sewing needle in contact with the south pole of a magnet; let the needle remain in contact for a few minutes; on separating them you will find that the pointed extremity has become a north pole, and the other a south pole.

Here it will be observed, that the end of the needle in contact with the pole of the magnet acquires an opposite or dissimilar magnetism to that of the pole. The equilibrium of the two magnetic fluids in the needle, is disturbed by the pole of the magnet, at the point of the needle, the dissimilar magnetic fluid is attracted by the pole, and the similar fluid is repelled.

Exp. 2. Rub one end of the needle, in the same direction, across the north pole of the magnetic bar, and then rub the other extremity of the needle across the south pole of the bar; then the former extremity of the needle will be a north magnetic pole, and the other extremity a south magnetic pole.

Exp. 3. Place the needle across the two poles of a horse-shoe magnet; let it remain there for some time; on removing it you will find that the extremity in contact with the north pole of the magnet has become a south pole, and the other a north pole.

Exp. 4. Place the middle of a needle on the north pole of a magnet; on separating them, you will find that the middle of the needle is a south pole, and that its extremities are north poles. This will form a pretty good astatic needle.

Exp. 5. With the pole of a good magnet, draw any figure upon the surface of a clear steel plate; sprinkle iron filings upon it; the filings will remain suspended at all those points which the pole of the magnet has touched.

Exp. 6. Place one pole of a magnet in the middle of the steel bar; draw the magnet along to the end of the bar; return the magnet, through the air, to the middle of the bar, and repeat the stroke in the same direction; repeat this operation for several times. Next place the other pole of the magnet in the middle of the steel bar, and proceed as before, observing that, in this case, the magnet must be drawn to the opposite extremity of the steel bar.

This process has been called the method of *single touch.*

THE METHOD OF DOUBLE TOUCH.

This process consists in touching the steel bar which we wish to magnetise with both poles of the magnet at the same time. This method is always employed when large steel bars are to be magnetised.

Fasten two bar magnets together, so that their dissimiliar poles may be about $\frac{1}{8}$ of an inch asunder; this will be most readily effected by inserting a piece of card-paper between them, and tying them with a piece of cord. Place this double magnet vertically upon the middle of the steel bar; draw the magnet to the end of the bar; return the magnet, through the air, to the other end of the bar; draw the magnet, as before, to the opposite end; repeat this process for several times, taking care to keep the pole of the compound magnet always in the same relative position, and to stop the process when the magnet has arrived at the middle of the bar. The operation should be performed on both sides of the bar.

A horse-shoe magnet, having its poles near together, will answer the same purposes as the double magnet just described.

This method may be employed to magnetise two or more bars at the same time.

Place two steel bars, N S, N S, of the same size parallel to each other, and connect their extremities with two pieces of soft iron, A and B (see *fig*. 21.).

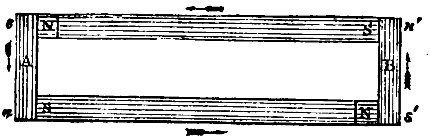


Fig. 21.

Place the pole of the double magnet on the middle of one of the steel bars, and move it completely round the frame, constantly keeping the poles of the double magnet in the same direction; when you have completed about a dozen revolutions, turn the plates and proceed as before. The poles of the steel bars will have a reverse position to the poles of the double magnet.

To magnetise Horse-shoe Bars.

Fig. 22. shows the method of magnetising one horse-shoe bar N. Place a piece of soft iron K, called a ***keeper***, across the extremities of the horse-shoe; place a horse-shoe magnet M, whose legs are at the same distance apart as those of the bar N, with its poles perpendicular to the keeper K; draw the magnet towards the bent part of the horse-shoe; when it has arrived there, lift it off, and bring

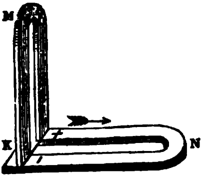


Fig. 22.

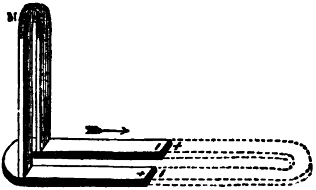


Fig. 23.

it back to its first position; repeat the operation for about a dozen times; then turn the horse-shoe bar with its keeper still on, and repeat the operation as before; and so on.

The polarity of each leg of the horse-shoe bar will be similar to that of the leg of the magnet first placed in contact with it.

Fig. 23. shows the method of magnetising two horse-shoe bars at the same time. The bars are placed with their extremities in contact, and the horse-shoe magnet M is moved from the curved part of one bar to the curved part of the other, constantly in the same direction.

The following is also a convenient and efficient mode of arrangement (see *fig.* 24.) for magnetising bars.

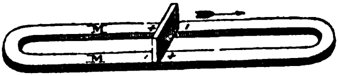


Fig. 24.

M M, is the horse-shoe magnet, placed with its poles against the extremities of the horse-shoe bar to be magnetised; **A** is a soft iron keeper extending between the legs of the horse-shoes; this keeper, or feeder, is drawn in the same way as the magnet represented in *fig.* 23.

In the same, straight bars may be magnetised.

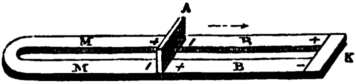


Fig. 25.

In *fig.* 25., **M M** represents the magnet, **A** the feeder, **B B**, the two bars to be magnetised, and **K** their keeper.

When magnetic bars are not in use, they should always be put away with their keepers upon them; this not merely preserves their magnetism, but also tends to increase it.

A compound horse-shoe consists of a number of horse-shoe magnets bound together by screws, and connected at their poles by means of a keeper, as shown in *fig.* 26.

Fig. 27. represents a lot of bars bound together in the same manner.

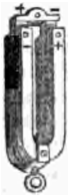


Fig. 26.

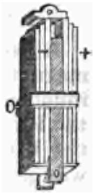


Fig. 27.

On the best quality of Steel for making Magnets.

"The steel best suited for artificial magnets is of a fine grain, of uniform structure throughout, and free from flaws. A principle requisite is, that it should possess a proper degree of hardness, and that it should be equally hardened throughout the entire mass; for, if too hard, it is extremely difficult to impart to it any magnetic virtue; and, if too soft, it readily loses it when given. It has been found most advantageous to make the steel in the first instance brittle, like glass, and then to heat it a second time, till it becomes of a straw or violet colour.

The capacity and tenacity of artificial magnets are also affected by their form and dimensions. It has been ascertained that the breadth of a bar magnet should be about one-twentieth of its length, and its thickness from one-fourth to one-third of its breadth. In a horse-shoe magnet, the space between the two poles ought not to be greater than the thickness of the bar of which the magnet consists. Lastly, it is necessary that both bar and horse-shoe magnets be well polished, and that their faces be as level as possible.

Magnetism is readily excited in soft Iron Bars.

A bar of soft iron, placed in the direction of the magnetic dip, becomes magnetic, from the inductive influence of the earth acting like a magnet upon the bar. A few blows applied at one extremity of the bar, thereby causing its particles to vibrate, will generally aid the inductive influence of the earth.

A bar of iron heated to redness, and allowed to cool after being placed in the direction of the magnetic dip, will acquire a certain degree of magnetism. Hence, pokers and iron rails, which have been kept for a long time standing in a somewhat vertical position, are generally found to possess a low degree of magnetism.

A piece of iron wire may be rendered magnetic by twisting it until it breaks; and in like manner files and gimblets, after having been some time in use, become so much magnetised as to attract iron filings.

Voltaic electricity is the most powerful means of rendering bodies magnetic.

Experiment. Allow a magnetic needle N S, to assume its north and south direction: take a non-magnetised poker and hold it in a horizontal position, and at right angles to the direction of the needle, so as to bring one of its extremities, say its lower extremity, near to the north pole of the needle; the needle will of course, be attracted if the poker is not magnetic; now hold the poker in the direction of the magnetic dip, as shown in *fig.* 28., and the north pole N, will be repelled, thereby showing that the lower extremity *n*, of the poker is a north magnetic pole. The effect will be increased by striking the head *s*, of the poker with a hammer.

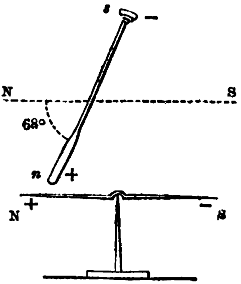


Fig. 28.

TERRESTRIAL MAGNETISM.

In order to account for the directive and dipping properties of the needle, it has been stated, that we must regard the earth as a great magnet, having a negative magnetic pole lying towards the north geographical pole, and a positive magnetic pole lying somewhere towards the south geographical pole. The following experiment is highly calculated to illustrate this theory.

Experiment. Place a magnetic needle (see *figs.* 29. and 30.) *n s*, over the middle part, A, of a magnetic bar N S; in this position the needle is exactly horizontal, and the south pole of the needle is directed to the north pole of the magnet, and the north pole of the needle to the south pole of the magnet. Thus we can assign a cause for the directive property of the needle. Now slowly move the needle along the bar from A to S; at the posi-

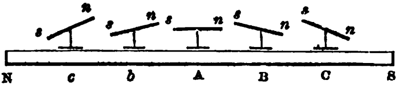


Fig. 29.

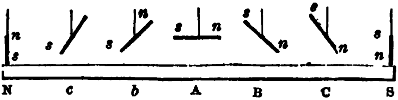


Fig. 30.

tion B, the north pole of the needle dips towards the south pole of the magnet; at the position C, the north pole of the needle dips still more towards the the south pole of the magnet; and at S, the needle hangs vertically with its north pole pointing to the south pole of the magnet. Now in like manner move the needle from A to N; at the position *b*, the south pole of the needle dips towards the north pole of the magnet; and so on as before. (In *fig.* 30., the needle is supposed to be suspended by a thread.) Thus we can account for the magnetic dip.

The phenomena of the direction and dip of magnetic needles at different parts on the earth's surface, are found to coincide with the effects which a bar magnet produces on the needle, as above described; hence we are led to conclude that the earth is a great bipolar magnet, whose poles lie towards the geographical poles of the earth. As like poles attract and unlike poles repel each other, it follows that the magnetic pole of the earth lying towards the north is a negative magnetic pole, and that the one lying towards the south, is a positive magnetic pole. The former magnetic pole is situated in North America, in the vicinity of Hudson's Bay, in 70° 5′ N. lat., and 114° 55′ W. long.; and the other in 72° 35′ S. lat., and 152° 30′ E. long. At these places, the dipping needle assumes a vertical position, as shown at P and K, *fig.* 31. Sir James Ross found the pole P, in the northern hemisphere during his arctic expedition of 1829. The actual existence of the magnetic poles in these places is further confirmed by the fact that the magnetic needle, at different parts on the earth's surface, is always directed towards these points as magnetic poles. At the MAGNETIC EQUATOR M T, the needle assumes a horizontal position. As we approach the magnetic pole P, the north pole of the needle dips more and more; and on the contrary, as we approach the magnetic pole K, the south pole of the needle dips more and more. On the MAGNETIC MERIDIAN K G P, K V P, &c., the needle has always the same general direction, although it varies in its dip. Let N S, represent the axis of the earth, E Q, its geographical equator, S V N, a geographical meridian; K V P, K X P, magnetic meridians; then the angles P V N, and P X N, will be the declinations, or angles of variation, of the magnetic needle at the points V and X, respectively. The commander of a ship at V, knowing from his charts the deviation of the needle at the particular spot, will be able to ascertain the true north and south. The

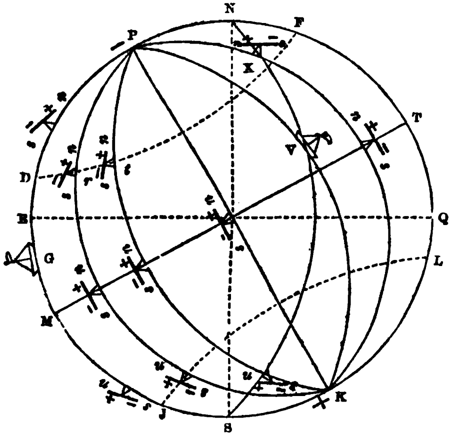


Fig. 31.

MAGNETIC PARALLELS D F, J L, &c., are LINES OF EQUAL MAGNETIC DIP, as shown at *r* and *t*, on the magnetic parallel D F, where the needles *s n*, *s n*, dip towards the pole P, at the same angle.

It must be borne in mind that these different magnetic lines upon the earth, are not exactly formed by true sections of the sphere like the geographical circles. Indeed some of these magnetic lines have the shape of looped curves, or curves of double curvature, differing more or less from the circular lines shown in *fig.* 31.

The lines of equal dip have been called ISOCLINIC LINES; these lines, as we have shown, surround the globe, running nearly parallel with the magnetic equator. It a remarkable fact, that there is a coincidence subsisting between these lines, and the isothermal lines, or lines of equal heat upon the globe: this coincidence indicates that the earth's magnetism is intimately connected with terrestrial heat.

The inductive influence of the earth upon bars of soft iron (see *experiments*, p. 13. and 26.), bears a striking analogy to the induction of magnetism by ordinary magnetic bars. The magnetic effects of the earth are undoubtedly attributable to the inductive influence of terrestrial magnetism.

VARIATIONS OF THE NEEDLE.

The earth's magnetic powers are subject to both regular and irregular variations. These variations are indicated by the changes which take place, at the same place, in the declination and dip of the needle, and in its magnetic intensity.

The regular variations follow a certain law, which enables us to calculate beforehand the changes that in future will take place. These regular variations are either secular or periodic. The secular changes become only evident after the lapse of years, and the periodic are those which, as it were, oscillate within short periods of time.

Of all the secular variations, the declination is that which has been most observed, and which has been most exactly determined. The dip and intensity have only recently claimed the attention of philosophers.

About the year 1600, the needle at London pointed 4½° to the east of the North; 1660 it pointed due North; from which time it gradually deviated to the west of the North until the year 1818, when it deviated 24·3° to the west of North, which was its maximum deviation; but for the last 30 years its declination has certainly been decreasing, and in all probability it will continue to do so until it again becomes due North, then the declination will increase towards the East until the needle has again attained its maximum eastern declination, when it will again return.

All that is known with certainty relative to the dip of the needle, is that at present it is decreasing in Europe. The maximum dip of the needle at London took place about a century ago, when it was about 74°; since that time it has been going on decreasing, with great regularity, at the rate of 3′ annually. At London the dip of the needle at the present time is about 68°.

The variation of the magnetic intensity has but recently claimed the attention of experimentalists; however, it seems highly probable that this intensity is at present decreasing in Europe.

The compass-needle, also, undergoes diurnal and annual variations. These variations appear to be intimately connected with the heat of the sun. From sunrise to a little after noon, the north pole of the needle moves towards the west, and after that time it retrogrades towards the east until a little after sunset in the evening, when it remains nearly stationary until sunrise. The extent of these variations depends, not only on the time of the year, but also upon the situation of the place. In London, during the heat of summer, the variation is about 19′, whereas, in winter, it is only about 7′. In Paris, the summer variation is about 15′, and in winter about 9′. These variations disappear under the magnetic equator; and on the south of it they are found to exist in an inverted order.

The dip of the needle is also subject to daily variations, which also appear to depend upon the action of the sun's heat upon the earth; but they do not exactly accord with the daily variations of declination.

The variations of magnetic intensity also appear to depend upon the sun's heat.

The irregular magnetic variations are connected with certain electrical and meteoric phenomena, such as the aurora borealis, lightning, and even volcanic eruptions. A flash of lightning has been known to reverse the poles of a needle, and even to destroy its magnetism entirely.

THE DECLINATION COMPASS AND MARINER'S COMPASS.

This apparatus is used for observing and measuring the declination of the needle, or, conversely, for determining the north and south direction, or the meridian line, when the magnetic declination is known. It consists of a magnetic needle N S (see *fig.* 32.), delicately suspended by means of an agate or steel cap O, resting on a pivot. E F is a graduated circle, on which is read the division corresponding to the position of the needle. The needle, with its graduated circle, is placed in a circular box covered with glass. The instrument is usually furnished with a telescope A B, turning on a horizontal axis C D, which carries an air-level and a vertical quadrant A, divided to measure the angles described by the telescope. The box is capable of turning

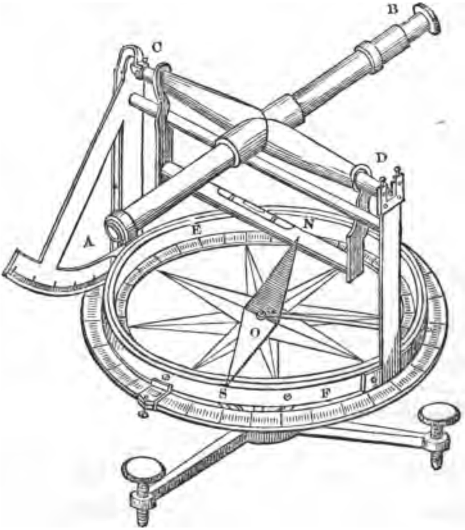


Fig. 32.

round on a vertical axis, by which it is fixed on its stand, in order to bring the telescope in the direction of the meridian; then the angle formed by the direction of the telescope, with the direction of the needle, gives the angle of declination; or, when the declination is known, the box is turned until the angle made by the axis of the telescope and the direction of the needle are equal to it; then this gives the position of the meridian.

The marine compass differs from the ordinary compass, simply in having a double suspension, which admits of its maintaining itself in a horizontal position, notwithstanding the rolling of the ship. *Fig.* 33. represents a form of this double suspension; where C is the agate or steel cap fixed to the needle N S; D another cap, with a pivot fixed to its upper part, on which cap C turns; A the pivot on which the cap D turns.

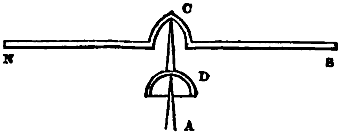


Fig. 33.

THE ASTATIC NEEDLE.

For the purpose of conducting many interesting experiments, it is requisite to have magnetic needles, on which the earth does not exert any directing influence: needles of this sort are called *Astatic needles.* This object is readily attained by fixing two equal needles to a common point of suspension, with their contrary poles together. By this means the one needle exactly counteracts the directive tendency of the other, so that the compound or astatic needle will be free to obey the slightest attractive force, without being influenced by the magnetic power of the earth.

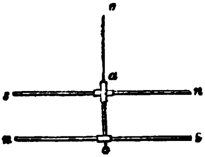


Fig. 33*a.*

Fig. 33*a.* represents a simple and highly serviceable astatic needle; *s n* and *n s* are two magnetic needles, of the same size and magnetic intensity, connected at their centres by a wire *a b;* the astatic needle thus formed is suspended by a fine thread of untwisted silk *a c.* The application of this astatic needle will be noticed in connection with the subject of electro-dynamics.

The inclination compass.

This apparatus is used for observing and measuring the dip of the needle at different places on the earth's surface, or at different periods of time at any place. See *fig.* 17. p. 18.

AMPÈRE'S THEORY OF MAGNETISM AND ELECTRO-DYNAMICS.

Ampère considered that a magnet is formed by a magnetic current, which he believed to be the same as an electric current, circulating round it constantly in the same direction, as shown in *fig.* 34. Supposing the magnet to have its north and south direction; then the current enters at the south poles, and circulates round the magnet spirally (like a corkscrew), along its length

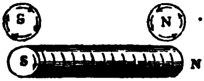


Fig. 34.

from south to north, as shown in the figure; that is, the current is directed from east to west in the lower face of the magnet, and therefore from west to east in its upper face; or, in other words, the current is ascending in the face situated on the west, and descending in the face on the east. Steel bars become magnets when this regular current is permanently excited in them. Ampère established this theory by showing, that a helix of copper-wire, through which an electric current is transmitted, possesses all the properties of a magnetic needle. As a necessary consequence of this theory, it follows that parallel currents moving in the same direction mutually attract, and that they mutually repel when they are moving in a contrary direction. Now wires conducting electrical currents have really this property. This explains why like poles repel and unlike poles attract. But this theory will be more fully explained in connection with the subject of electro-dynamics.

VOLTAIC ELECTRICITY.

Galvanism or Voltaic Electricity is produced by a certain chemical action upon two different metals when brought into contact. Galvani, of Bologna, observed that when he touched a nerve and muscle in the leg of a dead frog with two different metals, on bringing these metals into contact, the leg underwent a convulsive motion, as shown in *fig.* 35., where Z and C are the two metals brought into contact at A, the extremity B being in contact with the nerve, and D with the muscle. Galvani considered this effect as due to something in the animal structure, and hence he called it *animal electricity*, but, out of respect to the discoverer, the name of *galvani electricity* was given to it. But Volta soon after showed, that the effect was entirely due to the production of electricity by the action of the two metals upon each other, and that the nerves and muscles of the animal merely exhibited the free electricity, in the same way as any other delicate electroscope might do. This leading conception conducted him to a series of splendid discoveries, and in particular in the first year of the present

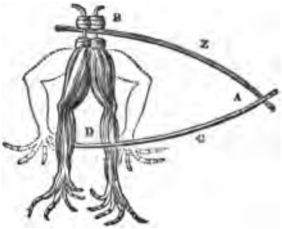


Fig. 35.

century, led him to the construction of the voltaic pile, which stands in the same relation to voltaic electricity that the common electrical machine does to frictional electricity.

VOLTAIC PILE.

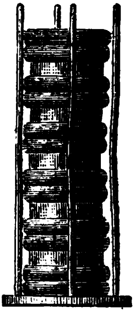


Fig. 36.

A number of circular plates of copper and zinc, and of cloth or card, about 3 inches diameter, were provided, and arranged in the form of A PILE, *fig.* 36. The base of the pile is a copper disc, upon which a zinc disc is placed (these two discs form what is called a pair); over this pair a second similar pair is placed, observing always that the copper is below the zinc; the second pair is separated from the first by the circular cloth or card, moistened with a weak saline or acid solution. Upon the second pair is placed a third, separated also by a moistened circular piece of cloth or card, similar to that which preceded. In this manner a considerable number of pairs are placed in the same order, one over the other, and retained in their upright position by means of rods of glass. When the base-plate of the pile rests upon an insulating plate of glass, this lower plate is found to be charged with negative electricity, whilst its upper plate is charged with positive electricity. These extremities are called the poles of the pile or battery, the lower extremity being the negative pole, and the upper extremity the positive pole. If the metals had been placed in a reverse order, then the poles would also obviously be reversed. Two wires. one leading from the extreme copper-plate;

and the other from the extreme zinc-plate, conduct the electricity of the respective poles to any substance upon which the electric fluid is required to act. When the extremities of these wires are brought together, an electric spark passes between them, arising from the neutralisation of the two different kinds of electricity. When these wires are held one in each hand (the number of pairs in the pile being sufficiently great), a rapid succession of shocks are felt. When the extremities of the two wires are connected by a very fine platinum or silver wire about half an inch in length, the neutralisation of the two electricities causes this fine wire to rise in temperature, and to become red-hot. The length of the fine wire, which may thus be rendered incandescent, is in proportion to the power of the pile.

When the two wires proceeding from the two poles of pile are immersed near each other in acidulated water, the water is decomposed into its two constituent gases, hydrogen and oxygen, the oxygen being liberated from the wire proceeding from the positive pole, and the hydrogen from the wire proceeding from the negative pole; the volumes of the gases are constantly in the same proportions that constitute water; that is to say, one volume of oxygen to two volumes of hydrogen, as shown in *fig.* 37. In this experiment, the submerged parts of the two wires must be platinum.

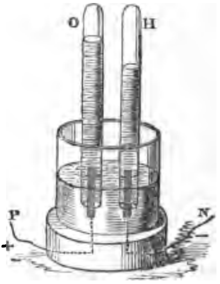
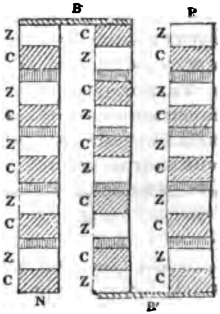


Fig. 37.

These phenomena are merely simple examples of the various and important effects produced by the action of the voltaic pile or battery, which we shall hereafter more fully consider.

When the number of pairs in the pile is so great that its height would be inconvenient when placed in a single column, the plates may be arranged in two or more columns, as shown in *fig*. 38., where the continuity of the pile is sustained by the bars B and B′. In this case the negative pole of the pile is at N, and the positive pole at P, and the effect of the whole is the same as if the second were placed over the first, and the third over the second.

Fig. 38.



Volta proposed a second arrangement of the pile or battery, called the *Couronne de Tasses.*

This form of the apparatus is represented in *fig*. 39.; it consists of a series of cups or glasses,

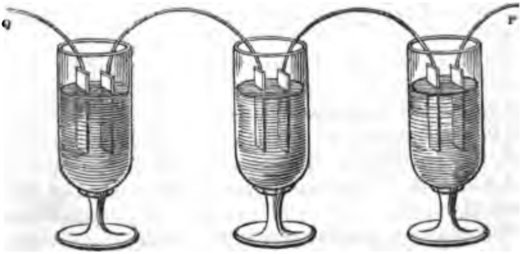


Fig. 39.

containing a saline or acidulated solution. Each pair of copper and zinc plates is immersed in the separate cups; the zinc plate in one cup being connected by a wire with the copper plate in the succeeding cup, and so on; the wire Q, proceeding from the first zinc plate, forms the negative pole of the battery, and the wire P. proceeding from the last copper plate, forms the positive pole of the battery; the same, in matter of fact, as in the ordinary pile just described.

Very great improvements have been made in the construction of these batteries; but before we proceed to describe them, we shall give a few simple and instructive experiments, calculated to elucidate the general principles and effects of voltaic electricity.

PRELIMINARY VIEWS AND SIMPLE EXPERIMENTS ON VOLTAIC ELECTRICITY.

Exp. 1. Place a piece of sheet-zinc *under* your tongue; lay a half-crown *upon* the tongue; no peculiar sensation is felt so long as the two metals do not touch each other: now bring the edges of the two metals in contact with each other; a disagreeable taste, something like copperas, is instantly excited.

Here the saliva on the tongue between the two metals is the exciting cause of the development of the electric fluid; and when the edges of the metals are brought into contact, the voltaic circle is formed, and the peculiar sensation of taste is the effect; but when the voltaic circle is broken this sensation instantly ceases. The peculiar taste of porter, when drunk out of a pewter pot, is also due to the same cause.

Exp. 2. Instead of the half-crown, in the last experiment, use a piece of charcoal or a piece of cast-iron.

Exp. 3. The first experiment gave you a *taste* of voltaic electricity; now the following experiment will give you a *sight* of it.

Place a silver spoon between the gums and one cheek, and a strip of zinc in a similar position on the other cheek; complete the voltaic circuit, by bringing the extremities of the metals together on the outside of the mouth; a slight flash of electric light will instantly be seen. Repeat the experiment: the flash will always be seen at the instant the two metals are brought into contact; and a smaller flash will be seen at the instant the contact is broken. The first experiment may be also performed by the silver teaspoon and the zinc-strip.

Exp. 4. Lay a five-shilling-piece on a larger plate of zinc; on the coin place a live leach or a live snail; so long as the creature does not come into contact with the zinc, he appears perfectly at his ease; but the moment he moves, so as to touch the zinc, thereby completing the connection between the two metals, he receives a shock and instantly recoils.

Exp. 5. Place a silver spoon s, in a glass containing a solution of sulphate of copper; into the same glass insert a strip of zinc z. No change takes place, in either of the metals, so long as they are apart: bring the upper ends of the metals in contact with each other; the silver spoon will become coated with copper, which will adhere so firmly that mere friction will not take it off.

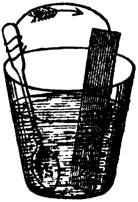


Fig. 40.

This experiment fully illustrates THE ELECTROTYPE PROCESS.

Exp. 6. Place a slip of copper C (see *fig.* 41.), in a glass containing hydrochloric acid; into the same glass insert a strip of zinc Z; so long as the metals remain apart, no chemical action can be seen, and no electricity is developed; bring the upper extremities *d*, of the metals into contact; active decomposition immediately begins; the chlorine combines with the zinc, and the hydrogen set free, makes its appearance at the surface of the copper in the form of minute bubbles,—voltaic electricity is in action. Withdraw the extremities of the metals from each other,—the electrical circuit is broken—electrical action no longer exists; restore the contact, and the electrical action is again renewed.

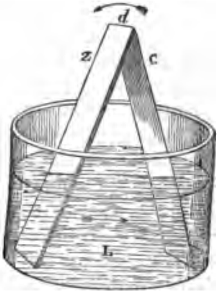


Fig. 41.

The disengagement of electricity is always in proportion to the chemical action; and the metal, which is most acted upon by the fluid, gives off its negative fluid to the other plate, and the consequence of this is, that the current proceeds from this latter plate to the former. In the experiment just given, the zinc plate is acted upon by the acid, and the voltaic current proceeds from the upper extremity of the copper plate to the zinc plate, as shown in the figure.

The cheapest acid for generating small portions of voltaic electricity with zinc and copper plates is sulphuric acid, diluted with about twelve parts of water to one of the strong acid.

Exp. 7. Bend the zinc Z, as shown in *fig.* 42.; place a bit of blotting paper, moistened with iodide of potassium, upon the zinc at A; bring the extremity B of the strip of copper C (or platinum), in contact with the moistened paper; the current of the electric fluid passes in the direction of the arrow; the iodide of potassium is decomposed by the electric current; the iodine is evolved at the positive pole, and the alkali, free potassa, at the negative pole.

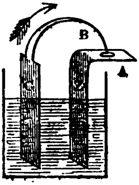


Fig. 42.

The experiment will be more striking if a drop of a solution of starch be also added to the moistened paper.

Exp. 8. Perform the same experiment with the bibulous paper moistened with prussiate of potassa, slightly acidulated with hydrochloric acid.

Exp. 9. Twist a piece of copper wire in the form of a spiral or helix, round a small glass tube; connect the extremities of the wire with the zinc and copper plates immersed in diluted sulphuric acid; insert a steel needle into the glass tube; after a short time the needle will be found to be powerfully magnetic.

Exp. 10. Bend a piece of soft iron wire H, into the form of a horse-shoe magnet; twist a piece of copper wire, covered with silk or cotton, round this wire as shown in *fig.* 43.; connect the extremities of this wire with the voltaic plates Z and C; the horse-shoe wire H, instantly becomes a magnet. If you have not got any covered wire at hand, wrap a piece of paper round the horse-shoe wire before you twist the copper wire round it.

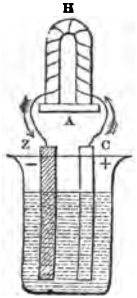


Fig. 43.

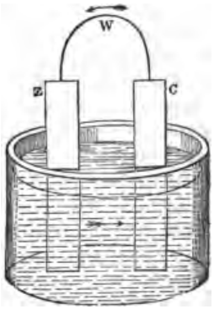


Fig. 44.

Exp. 11. Place the copper wire C Z, connecting the voltaic plates, in the plane of the magnetic meridian; bring a magnetic needle exactly over the wire C Z; the needle will be deflected from its north and south direction by the action of the wire C Z, conducting the voltaic current: now bring the needle exactly below the wire C Z; the needle will be deflected to the side opposite to that towards which it was before deflected.

REMARKS RELATIVE TO BATTERIES GENERALLY AND TO THE DIRECTION OF THE VOLTAIC CURRENT.

Fig. 45., represents a single pair of zinc and copper plates acted upon by a diluted acid; the connecting wire c z, shows the direction of the electric fluid; that portion of the copper plate which is immersed in the acid, becomes charged with negative electricity, and, as a necessary result of the law of electrical repulsion, the positive fluid is driven off from the upper extremity, hence the direction of the current. In all batteries, the current will always proceed from the wire attached to the metal least acted upon by the decomposing fluid.

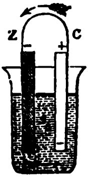


Fig. 45.

In Volta's battery, represented in *fig.* 39., of which all other batteries may be regarded as mere modifications, the wire P, attached to the last copper plate will be a positive or + pole, and the wire Q, attached to the first zinc plate will be a negative, or — pole.

Fig. 46. represents a voltaic arrangement of two plates Pt., Pt., of the same metal, viz. platinum, immersed in different fluids, A, an alkali, and *c*, concentrated nitric acid, separated by a porous partition *a b*. The platinum immersed in the alkali becomes positively electrified, and that in the acid negatively electrified, and the current flows as shown in the figure.

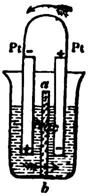


Fig. 46.

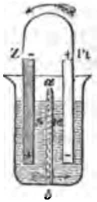


Fig. 47.

Fig. 47. shows the voltaic action which takes place, when different metals are immersed in different fluids. The platinum plate Pt., is immersed in concentrated nitric acid M, and the zinc plate Z, in concentrated sulphuric acid S, the two acids being separated from each other by the porous partition *a b*. In this case the most intense electromotive tension is excited, the one metal being immersed in that fluid which renders it most powerfully negative, and the other metal in that fluid which renders it most powerfully positive. This is the principle upon which Groove's battery acts, which is certainly the most powerful that has yet been constructed.

DIFFERENT FORMS OF THE VOLTAIC BATTERY.

Cruickshank's battery, represented in *fig.* 48., consist of an oblong trough of baked wood, divided into cells, to be filled with acid, by a number of pairs of rectangular plates of zinc and copper. This form was a decided improvement on the common pile, but still it had several inconveniences in practice.

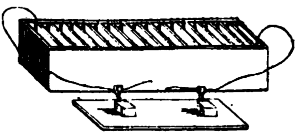


Fig. 48.

The arrangement represented in *fig.* 49., removed many of these inconveniences. It is merely a slight modification of the Couronne de Tasses, represented in *fig.* 39. The trough T, with its cells, is made of Wedgewood-ware; the plates of zinc and copper, forming each pair, are soldered together by a connecting rod at the top, leaving them sufficiently apart at the bottom to span the partitions of the trough. The plates, thus joined in pairs, are all attached to a wooden bar C D, by which they may

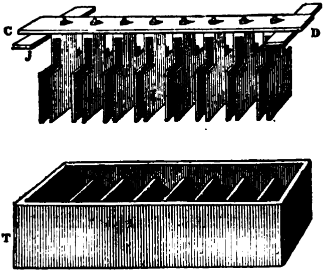


Fig. 49.

be readily let down into the trough, when they are required to be in action, or withdrawn from the trough when the action is to be suspended.

The greatest advantage attending this arrangement is, that by simply raising the plates, the fluid may remain in the trough while the action of the battery is suspended.

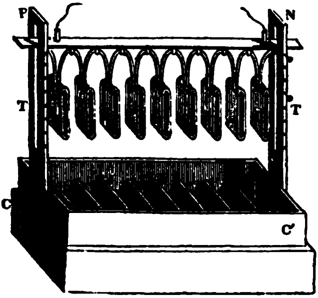


Fig. 50.

Wollaston's battery. Wollaston, having discovered that the effect of the foregoing battery was augmented by increasing the surface given to the copper, he enveloped the zinc plate of each pair with the copper plate of the preceding one, taking care, at the same time, to avoid all metallic contact between these two plates. By this arrangement, the copper plate has double the surface of the zinc plate.

Fig. 51. represents a more convenient form of this battery, where the trough is replaced by a series of glass jars. The acid can be more easily changed or discharged from these separate cells, than from the cells in the trough of the preceding form of the apparatus.

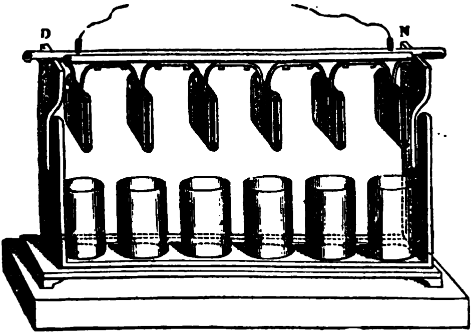


Fig. 51.

The Helical battery. In this battery the zinc and copper are wound into the form of a helix, and plunged into a glass vessel, containing the diluted acid; the helix of the zinc, in each pair, must not be in metallic contact with that of the

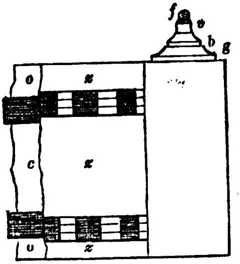


Fig. 52.

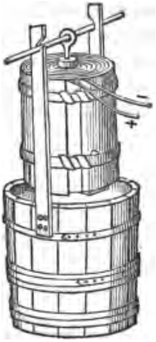


Fig. 53.

copper; but the helix of zinc in one vessel must be in metallic communication with the helix of copper of the succeeding pair, and so on, as in Wollaston's battery. *Fig.* 52. shows the manner of forming each pair of helixes, and *fig.* 53. the trough adaptation for each pair. This arrangement presents a great surface of metal in each pair to the action of the acid, without the necessity of having very large troughs. The acid mixture for charging this battery, is water mixed with $\frac{1}{40}$th in volume of strong sulphuric acid, and $\frac{1}{80}$th of nitric acid.

The batteries hitherto described, all have one decided inconvenience, viz., that after a short time they lose their power, which occasions them to act with a variable force during the same course of experiments. The zinc plates soon become covered with sulphate of zinc, and the copper plates with hydrogen and even oxide of zinc; these deposits not only greatly reduce the power of the battery when in use, but also require the plates to be cleaned before being put into action again. In order to avoid these inconveniences, Daniell, Grove, and Bunsen invented their constant batteries.

CONSTANT BATTERIES.

These batteries are constructed on the principle explained in connection with *fig.* 47., p. 46.; where the porous partition, without interrupting the conduction of the voltaic fluid, prevents the accumulation of depositions upon the plates.

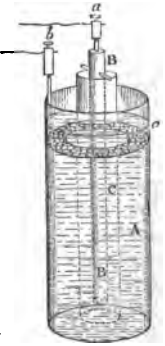


Fig. 54.

DANIELL'S CONSTANT BATTERY. A single pair of this battery is represented in *fig.* 54. A, is a copper vessel; C, a porous cell, into which is inserted a cylinder of amalgamated zinc B; *a* and *b*, are binding screws for connecting the respective metals with others in the series, or for attaching conducting wires when a single pair only is to be used. The cell C, into which the zinc dips, is filled with diluted sulphuric acid (one of strong acid to about twenty of water); and the copper vessel A, is filled with a saturated solution of sulphate of copper. So long as the poles *a* and *b*, are disconnected, no action will take place; but the moment the circuit is completed by connecting the screws *a* and *b*, a very powerful action occurs; the inner surface of the copper vessel becomes gradually covered with a layer of pure copper, and the porous cell C, becomes charged with sulphate of zinc. This process tends to deprive the solution of sulphate of copper of its copper, and to neutralise the sulphuric acid by the dissolution of the zinc ; in order therefore to sustain the action unimpaired, some crystals of sulphate of copper are placed upon a perforated shelf *c*, in contact with the solution.

Fig. 55., shows the manner in which a series of these cells are connected so as to form a battery.

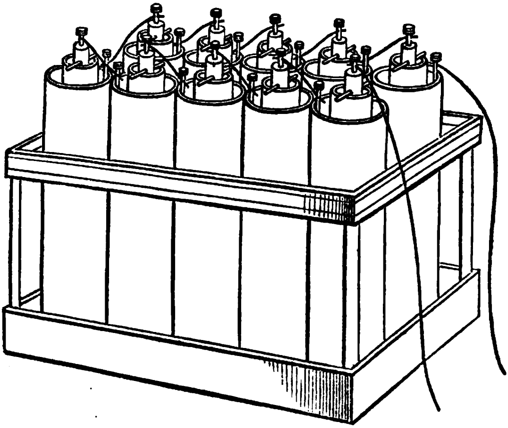


Fig. 55.

The advantages of this battery are as follows :— (1.) The solution of the zinc is kept apart from the copper by the porous cell. (2.) The hydrogen, instead of escaping, as in the ordinary batteries, combines with the oxygen of the oxide of copper, and precipitates pure copper upon the side of the copper vessel, and does not in the slightest degree affect the action of the battery. (3.) There are no noxious fumes arising from the action of the battery. (4.) The amalgamation of the zinc, without at all affecting the production of electricity by the battery, prevents the zinc from being dissolved by the sulphuric acid when the battery is not in use, that is to say, when its poles are not united by a conductor; but the moment this union takes place, the zinc is attacked by the acid, just as if the mercury were not there, only the oxide that is formed does not adhere to the surface of the metal, which it would do if the zinc were not amalgamated, and would thereby tend to weaken the action of the battery. Plates of zinc are very easily amalgamated, by pouring mercury upon the zinc, and at the same time keeping rubbing it on the surface with a piece of chamois leather dipped in diluted sulphuric, which cleans the surface of the zinc, and thereby brings the mercury and zinc into combination.

GROVE'S BATTERY. This battery is constructed on the same principle as that of Daniell's, that is to say, the plates are acted upon by two liquids separated from each other by a porous earthenware partition. The pairs of plates are composed of amalgamated zinc Z, and platinum foil Pt, plunged into a cell A B C D, composed of glazed porcelain or glass. The cell A B C D, is filled with diluted sul-

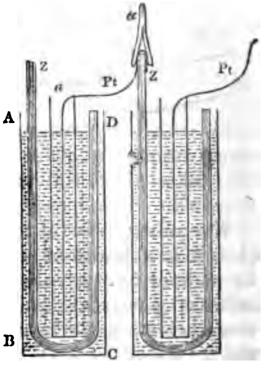


Fig. 56.

phuric acid, which acts directly upon the zinc; and the porous cell *a*, into which the platinum is plunged, is filled with nitric acid. The platinum plate Pt, is in metallic contact with the zinc of the succeeding cell, as shown at *a*; and so on to the whole series of cells in the battery. As the power of these batteries is much increased by giving to the zinc plates a very large surface as compared with the surface of the platinum plates, the zinc plates are bent round the porous cell *a*, so that they form in each cell two vertical surfaces, united by a horizontal surface at the bottom.

When the poles of this battery are united, so as to bring it into action, the hydrogen, arising from the decomposition of diluted acid, does not attach itself to the platinum, but goes to change the nitric acid into nitrous acid; the oxide of zinc remains, as in Daniell's battery, in the cell of the diluted acid, without penetrating through the porous cell to the platinum, which consequently remains perfectly clean; this circumstance essentially contributes to keep up the power and constancy of the battery, which render it so valuable as a voltaic combination. After a time, however, the nitrous acid, which is constantly formed, acquires a high temperature and gives off deleterious fumes; when this takes place, the action of the battery should be arrested. This battery, for almost every purpose, is the most powerful that has yet been constructed. About half a dozen cells, with a platinum surface in each of ten square inches, will be found sufficiently powerful for performing all the most interesting experiments connected with voltaic electricity.

Bunsen's battery differs from Grove's only in charcoal being substituted for the platinum. The cells of this battery have the cylindrical form, represented in *fig.* 57., in consequence of the carbon or charcoal being best made in the form of

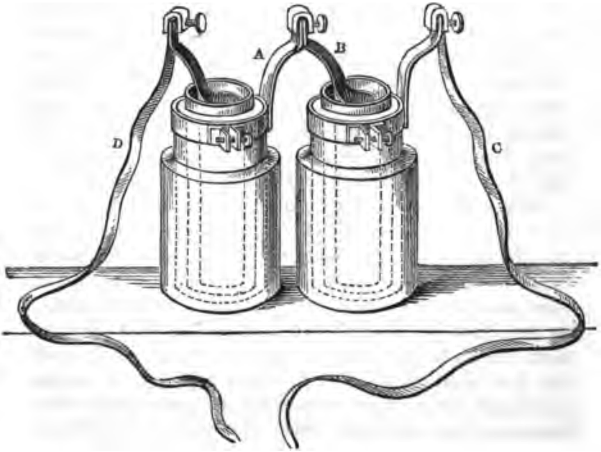


Fig. 57.

hollow cylinders. The strip of copper A B, shows how the zinc of one cell is united with the carbon cylinder of the succeeding cell; and so on. The figure also shows how the strips of copper C and D, forming the poles of the battery, are connected with the extreme cells of the battery.

Each charcoal cylinder, usually carries a collar of copper at its upper end for the purpose of fixing the connecting strip of copper to it; this copper stands above the glass vessel so as not to come in contact with the nitric acid; however, it is found that, owing to the porous nature of the charcoal, the acid, to a certain extent, rises to the copper collar, and in time destroys its efficiency. The following contrivance, see *fig.* 58., completely remedies this inconvenience: the charcoal cylinder C, is solid, and into its top is thrust a stout copper rod N M, which is bent so as to be brought into contact with the succeeding zinc cell. To prevent the acid ascending to this copper rod, the top of the charcoal cylinder surrounding the wire is covered with a cement of wax.

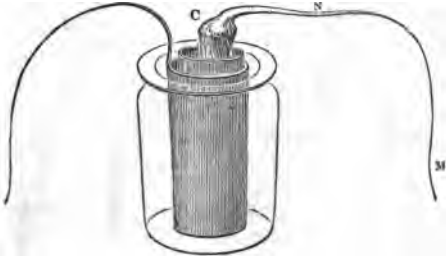


Fig. 58,

It is almost unnecessary to say, that the charcoal cylinder in this battery is plunged into the nitric acid, filling the porous tube or cell, and that this porous cell is placed within the cylinder of amalgamated zinc, which is surrounded by the diluted sulphuric acid filling the glass jar or porcelain vessel.

[This battery is comparatively cheap, and the author can state, from his own experience, that it possesses great power, and is easily brought into action.]

Smee's battery. In this battery the plates are acted upon by only one liquid, viz., diluted sulphuric acid (one part of acid to about seven parts of water.) *Fig.* 59. represents one of the cells of this battery. A, the earthenware cell filled with the diluted acid; Z Z, two vertical plates of amalgamated zinc, one on each side of the platinized plate of silver S; *w*, a bar of wood to which these plates are fixed; *b*, a binding screw which secures the zinc plates to the wooden bar. The connections are made, as usual, by means of the small binding screws shown in the figure. This forms a highly economical and efficient battery. Although its power may be less than Grove's battery, at the same time it is in many respects more convenient and agreeable for general use, especially for conducting experiments relating to electromagnetism.

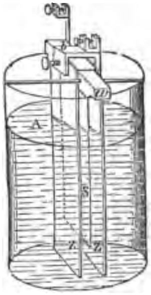


Fig. 59.

VOLTAMETERS.

These instruments are used for measuring the power of a battery. There are three kinds of voltameters at present in use; one of them depends upon the decomposing power of the battery, another upon its heating power, and the third upon its magnetising power.

It has already been shown how the poles of a battery resolve water into its constituent gases, hydrogen and oxygen. Now it is presumed that this decomposing power of a battery is in proportion to its general power, or rather in proportion to the quantity of electric fluid developed by the battery. Now in the gas voltameters, represented in *figs.* 60., 61., and 62., the quantity of gas liberated by the poles of the battery in a given time is taken as the measure of the power of the battery, or, what amounts to the same thing, the

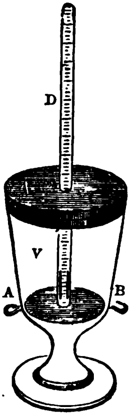


Fig. 60.

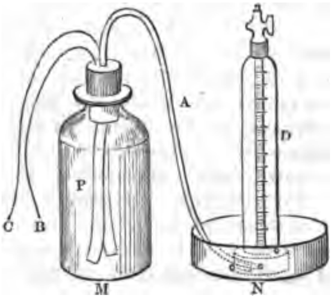


Fig. 61.

power may be measured according to the inverse ratio of the time requisite for liberating a given volume of the gas.

In *fig.* 60., the platinum poles of the battery are placed vertically in a graduated glass tube D; very near to each other; the lower extremities A and B, come out at the bottom vessel V, containing the water, so that a connection may be readily made between them and the wires leading from the extreme plates of the battery. The two gases in this instrument are received in the same tube; they may, however, be received in separate tubes, as in the instrument represented in *fig.* 37.; but in this case the platinum poles, being at a greater distance from each other, causes the decomposition to go on more slowly. When the battery has very great power, the gases are usually collected in a graduated receiver D, (*fig.* 61.) placed upon the pneumatic trough N; the decomposition of the water takes place in a bottle M, fitted up with a cork and bent tube A, for conveying the gases to the receiver D; the platinum poles or electrodes P, hanging near together within the bottle, are connected with the wires B and C, leading to the extreme plates of the battery.

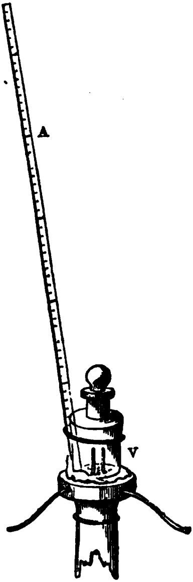


Fig. 62.

Fig. 62. represents an eligible form of this apparatus, when the liberation of gas is very feeble. The quantity of gas is measured by the amount of displacement of the liquid. A graduated tube A, proceeds laterally from the lower part of the vessel V, wherein the decomposition of the water is carried on, so that as the gases rise to the top of the closed vessel V, an equal volume of water is thrown up the tube A.

The three following voltameters depend upon the calorific effects of the battery.

Fig. 63. represents a voltameter, which is merely a slight modification of the common pyrometer. The platinum wire *a b*, forming a portion of the voltaic circuit, becomes powerfully heated and expands, and allows the pointer *a d*, to fall; the graduation on the quadrant indicates the amount of expansion, and consequently the relative power of the battery.

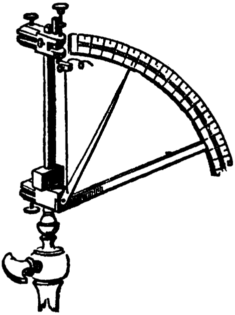


Fig. 63.

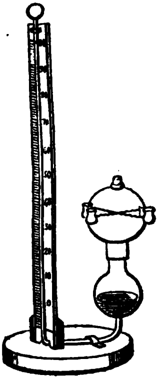


Fig. 64.

Fig. 64. represents a still more sensible voltameter, in which the platinum wire, forming a portion of the voltaic circuit, passes through the ball of an air thermometer; the expansion of the air by the heat of the wire, causes the liquid to rise in the vertical graduated tube; and so on.

The magnetic voltameter will be hereafter fully described.

EFFECTS OF VOLTAIC ELECTRICITY.

CHEMICAL EFFECTS.

THE chemical action of voltaic electricity upon different substances placed in the circuit, forms one of its most important and remarkable features. It has been shown that frictional electricity exerts a chemical action, but it is very feeble as compared with that which even small voltaic batteries exert.

One of the most remarkable facts connected with these decompositions is, that certain elements, into which the substances are resolved, always arrange themselves on the positive pole or electrode, and certain other elements always arrange themselves on the negative pole or electrode. Thus oxygen, chlorine, iodine, and the acids, always fly to the positive pole of the battery, and hydrogen, alkalies, oxides, &c., always fly to the negative pole; for example in the decomposition of water (see page 39.) the oxygen is accumulated in the tube placed over the positive pole, while the hydrogen is accumulated in that placed over the negative pole. This fact has led to the formation of a system of ELECTRO-CHEMISTRY. The respective poles are supposed to be in a contrary electrical state to the elements which they attract; hence, oxygen, chlorine, acids, &c. are negative elements, and alkalies, oxides, &c. are positive. Every chemical compound, therefore, consists of a negative element and a positive element, which are held united by the law of electrical attraction.

Exp. 1. DECOMPOSITION OF WATER. This is most elegantly performed by the apparatus described at page 39., but the following simple form of making the experiment is highly instructive.

Immerse a strip of amalgamated zinc, and a strip of clean copper into a glass of water slightly acidulated with sulphuric acid: so long as the metals are kept apart, no action can be observed, but the instant that the upper extremities of the metals are brought into contact the water is decomposed, numerous little bubbles of hydrogen collect round the copper, and the oxygen at the same time passes to the zinc and oxidises it.

Exp. 2. DECOMPOSITION OF NEUTRAL SALTS. Fill the two tubes of the apparatus represented in *fig.* 37. page 39., with a solution of sulphate of soda, or any other neutral salt, coloured blue with tincture of violets; then when the battery is in action, the acid will be attracted to the positive electrode, and will render the liquid in the tube red, and the alkali will be attracted to the negative electrode, and will tinge the liquid in the tube green; transpose the poles and the effects will be reversed.

Exp. 3. TO PRECIPITATE A METAL FROM THE SOLUTION OF A METALLIC SALT. *Fig.* 65. represents a simple piece of apparatus for producing this decomposition. *a*, is a glass tube about an inch in diameter, having a piece of bladder tied over its lower extremity, and suspended in a large glass vessel *b*; pour a solution of acetate of lead, (sulphate of copper, nitrate of silver, &c., will answer the purpose) into the glass tube *a*; fill the outer vessel with diluted sulphuric acid; into the solution of lead immerse

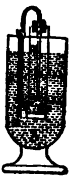


Fig. 65.

a platinum wire *p*, and into the diluted sulphuric acid plunge a strip of amalgamated zinc Z, in metallic contact with the platinum; then a voltaic circuit will be formed, consisting of two metals and two exciting fluids; the acetate of lead will be decomposed, the metallic lead will be attracted to the platinum, and the acid to the zinc.

The metallic vegetations called ***the lead tree***, &c. depend upon the voltaic action.

Exp. 4. Connect the tin-foil plate G, with the copper pole of a small battery, and the metal plate D, with the zinc pole of the battery. Lay a piece of white blotting paper, soaked in a diluted solution of hydrochloric acid and prussiate of potassia, upon the plate D; draw a number of strokes with a brush dipped in varnish across the plate G, as shown in *fig.* 66.; take a bent wire A, and connect the two plates with it; move the wire from end to end; then the electro circuit will be complete whenever the wire connects the metallic foil and the damp paper, and the circuit will be broken at those parts where the wire passes over the varnish; the solution on the paper will be decomposed at the former parts, but will remain unchanged at the latter parts, as will be shown by the deep blue marks formed upon the paper by the decomposition of the prussiate of potash.

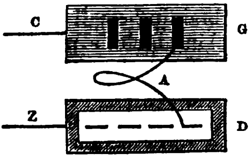


Fig. 66.

This experiment illustrates the principle on which the COPYING ELECTRIC TELEGRAPH is constructed.

Electrotyping.

The decomposition and reduction of metals, in a state of solution, by the voltaic battery, has led to some important discoveries in the arts, such as electrotyping, electroplating, &c.

The experiment given in connection with *fig.* 49. page 42. is a familiar example of electroplating; electrotyping depends upon the same principle.

Fig. 67. represents a very simple contrivance for obtaining small electrotype casts. A, is a glass vessel in which the mould from which the cast is to be obtained, is placed. B, is a glass tube suspended within the vessel A, by means of a metallic ring *d e*, to which are fixed three strips of metals. The lower end of this tube *m n*, is closed by tying a piece of bladder over it. The strip of brass *b c*, has two binding screws *b* and *a*, by which the wires *a* z, and *b* K, are secured; the lower extremities of these wires carry the substances z and *k*, which act as the electromotors or voltaic plates constituting the simple battery. Z, is an amalgamated zinc plate, suspended within the tube; *k*, is the body from which the cast is to be taken, laid on the spiral shaped-extremity of the wire *b k*; the model is the negative electromotor, and Z, the positive electromotor. The large glass A, contains a concentrated solution of sulphate of copper; this is always kept in a saturated state by having crystals of sulphate of copper suspended in it; the tube B, is filled with diluted sulphuric acid; the liquids should stand at the same level in

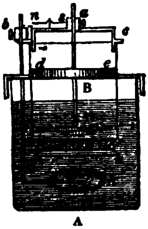


Fig. 67.

both vessels. According to this arrangement, the electric current passes from the zinc z, to the mould *k*; and pure metallic copper is deposited upon the surface of the mould, and in time forms a complete cast of the surface.

The following particulars should be attended to in making electrotype casts. The surfaces of the originals should be good conductors, and they should not contain any substances which would be acted upon by the sulphate of copper. The model may be of gypsum, wax, or any similar non-conducting substance, provided the surface of the model be covered with a metallic coating: plumbago dust or bronze powder, laid on with a camel's hair brush, forms a very good coating. A wax impression should be first slightly moistened with alcohol, and then the black lead should be rubbed over it with a stiff brush; the copper wire should then be warmed and pressed into the margin of the wax, the connection between the wax and wire should then be made with the black lead. A coating of wax dissolved in turpentine will protect any part of a coin from any metallic deposit. In every electrotype cast the elevated portions of the original will be depressed, and *vice versâ;* in order therefore to obtain exact fac-similes of the original, the first cast must be used as a matrix on which the coating of copper must be thrown by the electrotype process.

Fig. 68. represents a more convenient arrangement. *z* is the amalgamated zinc rod, suspended in the porous cell *p*, which contains the diluted sulphuric acid; *c*, the glass or earthenware vessel containing the solution of sulphate of copper; *w*, the copper wire connected with the zinc by a binding screw, and carrying at its lower extremity the seal or mould *m.*

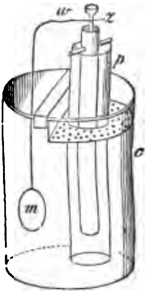


Fig. 68.

Fig. 69. represents another arrangement, where the current is generated in a distinct battery A; B, is a distinct vessel for conducting the electrotype process. *m,* is a metal rod for supporting the moulds, and *c,* another rod supporting copper plates, which form the positive electromotors; *x,* connects the moulds with the zinc in the battery, and *z,* connects the copper plates with the copper plates of the battery. The vessel B, contains two parts of saturated solution of sulphate of copper, and one part of sulphuric acid diluted with about seven parts of water. The action which takes place is simply as follows: the copper is consumed from the plates *c,* and deposited on the moulds *m*; so that the copper solution in the vessel B, remains unchanged in its strength from the commencement to the close of the process.

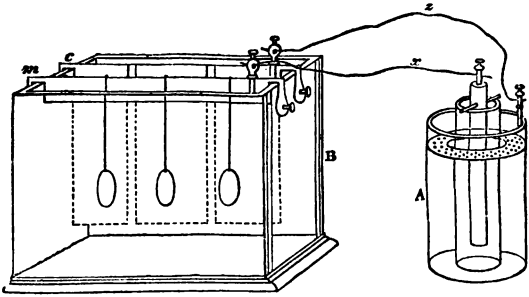


Fig. 69.

ELECTROPLATING EXPERIMENTS.

Exp. 1. Place a small plate of clean platinum foil in a saucer, and pour over it a solution of sulphate of copper covering it to the depth of about a sixteenth of an inch; touch the platinum plate with a pointed strip of bent zinc, the other end of which is kept in the liquid; different coloured rings of metal will be formed upon the platinum plate.

Exp. 2. The brilliancy of the depositions will be much increased by using a constant battery of three or four pairs of cells.

PROTECTION OF METAL PLATES BY VOLTAIC CURRENTS.

Voltaic currents not only affect combinations and decompositions, but they may also be employed for impeding or arresting certain decompositions which would otherwise take place by the ordinary laws of chemical affinities. Thus for example, Davy protected the copper bottoms of ships from the corrosion of the salt water, by connecting plates of zinc with the copper sheathing. In order to protect a metal from the chemical action of an acid or a saline solution, it is only necessary to combine the metal with some other metal in the fluid, which shall act as the positive electromotor.

Exp. 1. Place a copper plate in a saucer; pour some diluted sulphuric acid upon it; then the metal will be violently acted upon by the acid; now touch the copper with a strip of zinc, and the action on the copper will be instantly arrested; the action will now be transferred to the zinc, and the copper will remain unaffected by the acid, until the whole of the zinc be dissolved.

LUMINOUS AND HEATING EFFECTS OF VOLTAIC ELECTRICITY.

The most brilliant of all the effects of voltaic electricity is the arch of electrical light evolved between two charcoal points. This phenomenon may be exhibited with about a dozen pairs of Grove's or Bunsen's battery. This experiment may be most conveniently performed by fixing charcoal points (pieces of graphite answer best) to the rods of a universal discharger. The poles of the battery are respectively connected with the extremities of the rods, as shown in *fig.* 70., where the arch A B, represents the form of the voltaic light. The points must be first brought into contact with each other, and then gradually withdrawn until the arch attains its most brilliant appearance; the length of the arch of course varies with the power of the battery; that is, with batteries of average power, from three quarters of an inch to about an inch and a half. This arch of flame is not produced by combustion, for it may be exhibited with equal brilliancy in a vacuum, and even takes place under water.

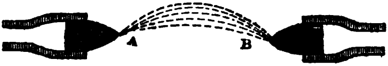


Fig. 70.

The intense heat of this electric arch will ignite the most refractory substances.

Exp. 1. Amalgamate the ends of the polar wires; bring them near together, while the battery is in action; a white starlike spark will be seen accompanied with a crackling noise similar to the emission of a feeble spark of frictional electricity.

Exp. 2. The spark obtained from these amalgamated points may be seen under water, or in the flame of a candle.

Exp. 3. Immerse one of the wires into mercury, and bring the end of the other wire near the surface of the fluid; a spark is emitted just before the wire touches the mercury, leaving a small black speck upon its surface.

Exp. 4. Coat the ends of the polar wires with soot, by holding them for a short time in the flame of an oil lamp; the sparks obtained from these coated wires will be much stronger and brighter.

The power of a voltaic battery, as we have already shown, is roughly estimated by the heat which it produces in a given conducting wire. The temperature to which a conducting wire will be raised by a battery, depends upon the length and thickness of the wire, as well as upon the nature of the metal, whether or not it is a good or a bad conductor of electricity. Short fine wires become most heated, and of all metallic wires, platinum, being the worst conductor of electricity, becomes most powerfully heated by conducting the electric fluid.

The calorific effect appears to depend more upon the size of the plates than upon the number of pairs; that is to say, it depends upon the quantity of the electric fluid evolved rather than upon its intensity or tension.

The calorific effects of the voltaic battery may be most conveniently shown, by stretching the wires to be heated between the extremities of the rods of the universal discharger (see *fig.* 70.).

Exp. 1. To show the heating power of a battery. Stretch a piece of fine steel wire between the poles of the battery; the wire, if it is not too long, will instantly become powerfully incandescent. If on the first trial, the wire only presents a dull heat, gradually reduce the length of the wire, until it glows with a white heat; reduce the length of the wire a little more, then it will be first fused, and then ignited.

The same experiment may be performed with platinum, or silver wire.

Exp. 2. Æther, alcohol, phosphorus, gunpowder, &c. may be readily ignited by making the hot platinum connecting wire to pass through them, or to touch some portion of them.

Exp. 3. If the platinum wire be conducted through a small portion of water, it will speedily boil.

PHYSIOLOGICAL EFFECTS OF VOLTAIC ELECTRICITY.

The relation between voltaic action and the nervous system of animals, was very carefully investigated at a very early stage of the history of voltaic electricity.

The peculiar nature of this relation is explained at page 37. of this work, when a small battery is employed. But with large batteries the effects are truly surprising. Dr. Ure thus describes his experiments upon the body of a full grown man, fifteen minutes after death. Upon applying one of the polar wires to the forehead, and the other to the heel, every muscle in his countenance was simultaneously thrown into fearful action; rage, horror, despair, anguish, and ghastly smiles united their hideous expression in the murderer's face. At this period several of the spectators were forced to leave the apartment from terror and sickness, and one gentleman fainted.

The physiological effects of voltaic electricity appear to depend upon intensity, rather than upon quantity, that is to say, upon the number of pairs in the battery, rather than upon their extent of surface.

The effect of the voltaic shock is much increased by attaching copper cylinders to the extremities of the conducting wires, and also by dipping the hands, by which the shock is received, in water slightly acidulated.

The magnetic effects of voltaic electricity are so various and interesting, that they have been treated as a distinct branch of electrical science, called *Electro-Dynamics.*

ELECTRO-DYNAMICS.

ELECTRO-MAGNETISM.

It has already been shown (*Exp.* 9. p. 44.) how a steel needle may be magnetised by passing a voltaic current through a wire helix. When a helix is wound to the right, or in the direction of a corkscrew, it is called a RIGHT-HANDED helix, as shown in *fig.* 71., and when the helix is wound in the contrary direction, that is, to the left, it is called a LEFT-HANDED helix, as shown in *fig.* 72. Helix wires should be formed of copper wire, covered with silk, for the purpose of insulating them.

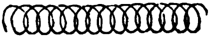


Fig. 71.

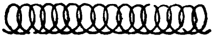


Fig. 72.

When a needle is magnetised by a current passing through a right-handed helix, or a corkscrew helix, the south pole of the needle is always at the extremity through which the currents enter, that is to say, at the extremity that is in connection with the positive electricity. On the contrary, when a needle is magnetised by a *left-handed helix*, the north pole is at the extremity which is in connection with the positive electricity.

These facts are in exact accordance with Ampère's theory of magnetism (see p. 35.); for the electric current moves round the magnetic bar in precisely the same manner as the magnetic current is supposed to do in that theory, thereby showing that the electric current which induces the magnetic condition is equivalent to the magnetic current upon which the ordinary magnetic condition is supposed to depend.

Let S N. *fig.* 73., be a right-handed helix, that is, a corkscrew helix, through which the electric current enters at S, and passes out at N; then, from what has been said, the helix will become a magnet, having the extremity S for its south pole, and N for its north pole. This may be tested experimentally by using *De la Rive's floating battery.* The extremities of the helix are connected with zinc and copper plates Z and C, fixed in a piece of cork, so as to make the whole apparatus to float in a strongly acidulated liquid. This float battery, like the floating needle, will place itself in the north and south direction of the needle; the extremity S, through which the current enters, will be directed to the south.

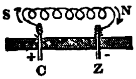


Fig. 73.

The Author has found the following form of this apparatus to be very convenient in practice.

B is a deal-board, having two concentric grooves E and F cut in it, and filled with mercury; the wires N and M connect the mercury in these grooves with the binding-screws C and Z, to which the poles of the battery are at-

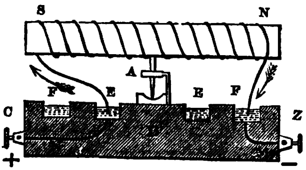


Fig. 74.

tached; S N is a corkscrew helix surrounding a soft bar of iron; one extremity of the wire dips into the mercury of the groove F, and the other into that of the groove E; the soft iron bar, with its helix, turns upon the pivot A. When the positive pole of the battery is fixed to the binding-screw C, and the negative pole to the binding-screw Z, the helix, with its soft iron bar, becomes an actual magnetic needle, and will settle itself in the direction of the magnetic meridian, the extremity S being directed to the south, and the other extremity N to the north.

If the soft iron bar be taken away, and a steel needle be inserted in its place, the needle will be magnetised, having the extremity towards S a south pole, and the extremity towards N a north pole.

Fig. 75. represents another form of the floating battery, where the copper and zinc plates are immersed in a glass tube, filled with the diluted sulphuric acid, and the whole is made to float in a vessel of water.

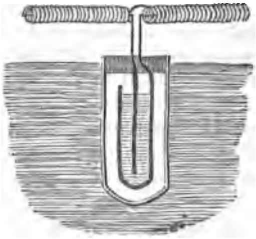


Fig. 75.

Electro-magnets of immense power may be formed by voltaic helices.

The Electro-magnet, or soft iron Horse-shoe Magnet.

Fig. 76. represents an electro-magnet; M is the soft iron bent in the form of a horse-shoe magnet; P and N are the extremities of the helix of covered

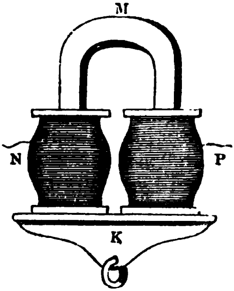


Fig. 76.

copper wire, surrounding the bar in the manner just described; K is the keeper of the magnet, from which a heavy weight may be suspended to show the power of the magnet. When the extremities, P and N, are connected with the poles of a single pair of any of our constant batteries, the soft iron instantly becomes a very powerful magnet, capable of supporting a weight of 1 cwt. to about 1 ton. The moment the connection is broken, the magnet loses its power. The wire, intended to form the coil, is cut into several portions, and is coiled separately on the iron, and then all the corresponding extremities are collected into parcels, which are soldered to a thick wire which communicates with the pole of the battery. By this arrangement, the current is divided into a series of short branches, which, collectively, communicate with the poles of the battery by a short strong wire; this gives energy to all the coils, and thereby increases the power of the electro-magnet.

These temporary magnets have been called *electro-magnets,* to distinguish them from permanent steel magnets, and *electric helices* just described.

Rotating Magnets.

The rotating magnet, invented by Dr. Richie, is represented in *fig.* 77. In this instrument a permanent rotatory motion is given to an electro-magnet, *c*, upon a vertical pivot, by means of the al-

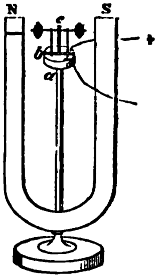


Fig. 77.

ternate attraction and repulsion of the poles, N and S, of a permanent horse-shoe magnet. In order to produce this continuous rotation, it is requisite that the poles of the electro-magnet should be reversed at every time they pass the poles of the permanent magnet; this is effected by a very simple and elegant artifice: *a b* is a wooden cup of mercury, divided into two compartments by a bridge or partition of wood, in a line with the poles N and S, whose upper edge is a little below the exterior edge of the cup; so that when the two compartments are filled with mercury, the cohesion of the particles of the fluid causes it to stand a little higher than the level of the top edge of the partition; the two extremities of the helix dip a little into the mercury without reaching to the level of the top of the partition, so that the electro-magnet may freely revolve upon its vertical pivot; the mercury in one of the compartments is connected with the positive pole of a small battery, and the other compartment with the negative pole; by this contrivance the poles of the electro-magnet are reversed at every time the dipping-wires cross the partition, and, consequently, if the poles of the permanent magnet attract the poles of the electro-magnet in any given position, they will be repelled the moment the dipping-wires have crossed over the partition, and thus the continuous rotation is sustained.

The following is a brief description of a rotatory magnet invented by the Author some twenty years ago, and employed by him in an extended form as a magnetic engine, capable of yielding about a quarter of a horse-power. The contrivance in this form was described in the "Mechanics' Magazine" for the year 1840. N S is the electro-magnet, turning upon a horizontal axis A B; N F and S E are the terminal wires of the coil; each of them forks off into two branches, F H, F J, and E K and E G; the extremities of the wires are connected with metal segments, H, J, K, and G, attached to the ivory wheels A and B, fixed to the common axis A B; the circumferences of these segments are placed concentric with the axis of motion, and their edges dip into mercury placed in the cups L and M, which are connected with the poles of the battery: by this contrivance the poles of the electro-magnet are changed when one pair of segments passes out of contact, and another pair comes into contact, with the mercury in the cups. The opposite poles of a permanent magnet are placed in a line with the electro-magnet when its position corresponds with the change of its polarity, as in the case of Richie's rotating magnet.

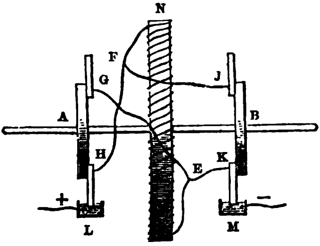


Fig. 78.

Contact-breakers.— Telegraphic Alarum-bell.

The two foregoing pieces of apparatus show how the poles of an electro-magnet may be reversed by changing the direction of the voltaic current. The contrivance represented in *fig.* 79., called a contact-breaker, shows with what rapidity an electro-magnet can acquire and lose its magnetism. M is a small electro-magnet, the armature of which, E, is capable of oscillating between the two poles of the magnet and a stop at its back, against which it is pressed by a spring. The conducting-wire D coils round the lower branch of the magnet, as shown in the figure, and the other conducting-wire, C, is attached to the stop, and then a wire passes from the foot of the oscillating armature to the extremity of the coil passing round the upper branch, M, of the electro-magnet; so that the electric current is complete when the armature is in contact with the stop, and it is broken when this contact is destroyed. The consequence of this arrangement is, the electro-magnet attracts the armature, which breaks the circuit, and the magnetism instantly ceases; then the armature, being pressed back by the spring, returns and strikes the stop, which again completes the circuit and renews the magnetism; the armature is again attracted by the magnet, and so on with great rapidity. The ad-

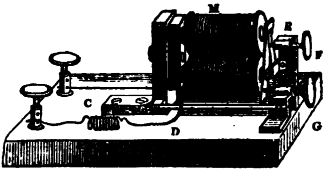


Fig. 79.

justing screws, F and G, enable the operator to regulate the rapidity of the strokes.

Telegraphic alarum-bell. To form this instrument into an alarum-bell, it is only requisite to fix a hammer to the top of the armature E, and to place a bell within the striking distance.

Instruments for measuring the Force of Magnets.

1. *Method of contact.*—The following is a simple contrivance for estimating the suspensive force of an electro-magnet. N J S is the electro-magnet; *p* and *m* the binding-screws to which the poles of the battery are fixed; A the feeder or armature, suspended from the extremity *a* of a graduated lever *a b*, turning on a fixed centre or fulcrum *c*; *h*, a sliding-hook, to which a scale-pan with weights may be attached. The weights, put in the scale-pan, necessary for breaking the contact of the feeder A, give the data for calculating the force of the magnet, on the simple principle of the lever of the first kind.

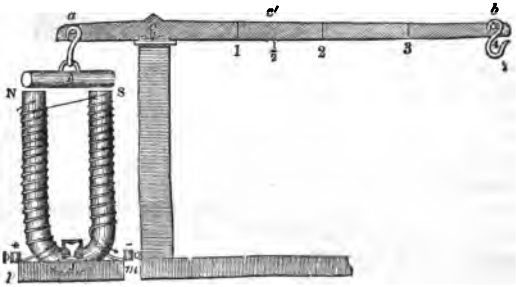


Fig. 80.

2. *Method of vibrations.*—The oscillations of a magnetic needle before it settles in its north and south direction, follow the same law as the vibrations of the pendulum. The directive force of a magnetic needle, therefore, may be measured by the number of oscillations that it will make in a given time, when drawn a little to one side of its magnetic meridian. When the same needle is employed to determine the directive force at two different places on the earth, this directive force varies as the squares of the number of vibrations performed in a given time.

The vibration of the needle is also employed to determine the intensity of the different points in a magnetic bar. In this case it is necessary that an allowance should be made for the directive force of the earth.*

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* By *Ex.* 7. and 8., page 252. Tate's Mechanical Philosophy, we have

$$g = \frac{\pi l}{t^2}, \text{ and } n = \frac{N}{\pi} \sqrt{\frac{g}{l}}$$

when g is put for the attractive force of the terrestrial magnetism, l the length of the pendulum, t the number of seconds in each vibration, n the number of vibrations performed in a given time N.

Now when l and N remain constant for any series of experiments, we have from the first

$$g \propto \frac{1}{t^2} \text{ or } t \propto \frac{1}{\sqrt{g}},$$

and from the second,

$$g \propto n^2,$$

that is to say, the intensity of terrestrial magnetism at different places on the earth's surface, as applied to magnetic needles, is inversely as the squares of the times of their vibra-

According to the experiments made by Coulomb, the attractive forces of the different points in a long magnetic bar, as estimated from the centre of the bar, increase in a geometrical progression as the distances from the centre increase in arithmetical progression.

TO MAGNETISE STEEL BARS BY THE ELECTRO-MAGNETIC COIL.

The simplest way of doing this is to coil a very stout copper wire covered with silk round a paste-

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tions, and directly as the squares of the number of oscillations performed in a given time.

Again, for the case of the magnetised bar, let g_1, g_2, g_3, be put; for the total action exerted upon it when successively made to vibrate before three consecutive points of the bar; n_1, n_2, n_3, the number of oscillations made by the needle in the given time N; then

$$n = \frac{N}{\pi}\sqrt{\frac{g}{l}}, \text{ and } n_1 = \frac{N}{\pi}\sqrt{\frac{g_1}{l}},$$

$$\therefore \frac{g_1}{g} = \frac{n_1^2}{n^2};$$

similarly,

$$\frac{g_2}{g} = \frac{n_2^2}{n^2}, \text{ and } \frac{g_3}{g} = \frac{n_3^2}{n}.$$

By combining these three equations we readily get,

$$\frac{g_1 - g}{g_2 - g} = \frac{n_1^2 - n^2}{n_2^2 - n^2}, \text{ and } \frac{g_1 - g}{g_3 - g} = \frac{n_1^2 - n^2}{n_3 - n^2}.$$

Now $g_1 - g$, $g_2 - g$, $g_3 - g$, represent the magnetic forces residing in each of the three points of the magnet; these forces may be compared with each other, when we have determined by experiment the values of n, n_1, n_2, n_3.

board tube, about 18 inches long and 2 inches diameter. The bar, A B, to be magnetised is placed between two soft iron cores, A Q and B D, made exactly to fit the interior of the paste-board tube E F. The whole is placed within the tube, and the extremities, C and Z, of the helix are connected with the poles of the battery: in a short time the steel bar, A B, will be magnetised to saturation.

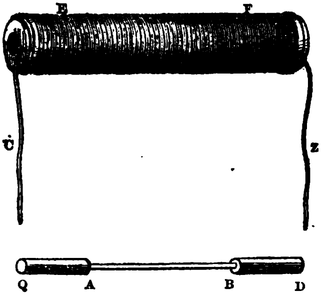

Fig. 81.

ON THE ACTION OF ELECTRIC AND MAGNETIC CURRENTS.

In addition to the magnetic effects of electrical currents, which have just been noticed, the following general laws of electrodynamics have been established.

General Laws of Electrodynamic Action.

1. Every metallic conductor through which an electric current passes, acts on magnets suspended freely, and shows magnetic properties.
2. Electric currents exert on each other influences like those which they exert on magnets.
3. A magnet acts on an electric current precisely as another current would do.
4. Electric currents in conductors in like manner excite such currents.
5. Magnets can, in like manner, excite electric currents, and the other electric influences dependent on them.

It must be observed, that the condition essential to these effects is, that the electric fluid must be in a state of motion, that is, it must be in the form of a continuous current, or, in other words, it must be in the condition which is called *dynamic;* there is no action when the electricity is in the *static* or *tension* state.

ACTION OF ELECTRIC CURRENTS ON THE MAGNETIC NEEDLE.

Oersted's Experiment.—Place the conducting wire, A B, of a battery in the direction of the magnetic meridian, viz., B towards the north and A towards the south, as shown in *fig.* 82.; suspend a

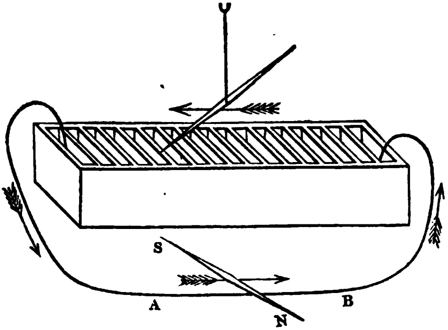

Fig. 82.

needle S N *over* the conducting wire A B, and the north pole N will be deflected to the east; suspend the needle *below* the conducting wire A B, and its north pole will be deflected to the west.

The needle, therefore, endeavours to assume a position perpendicular to the direction in which the electric current flows.

Ampère represented the action of the electric current on a magnetic needle under a form which is easily remembered. "We have only to conceive a man lying down in the portion of the circuit under consideration, in such a manner that the current enters by his feet, and goes out, consequently, by his head: furthermore, we have but to conceive that this man has always his face turned towards the needle, so as to look at it; then the action is always found to be such that the north pole of the needle is deviated to the left of this man. This formula comprehends all possible cases."

It is easy to see that the positive current, coming from the positive pole of the battery, passes along the conductor and arrives at the negative pole, and returns through the plates of the battery to the positive pole; so that the current has a different direction in the two parallel portions of the circuit, as shown in *fig.* 82.

All these effects are perfectly in accordance with the theory of magnetic action, explained at p. 35. The needle seeks to place itself at right angles to the direction of the current, on the principle that the electric current in the magnet seeks to place itself parallel to the current in the wire.

Galvanometers. The Electric Telegraph.

We have explained the construction of certain voltameters or galvanometers depending upon the calorific and chemical effects of the voltaic current; but the most perfect instrument of this kind is that which depends upon the magnetic effects of the current.

The most simple magnetic galvanometer is represented in *fig.* 83. A magnetic needle, *n s*, is suspended between two conducting parallel wires, *w* and w, terminating in the mercury cups, P and N. The conducting wire is placed in the direction of the magnetic meridian, so that the needle has the same direction as the wires. When the poles of the battery are in-

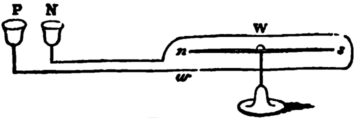

Fig. 83.

serted in the cups, P and N, the needle is deflected after the manner described in the foregoing section. According to this arrangement, the conducting wire above the needle, as well as the wire below it, tends to deflect the needle in the same direction, so that the double wires exactly double the amount of deflection. The angle of deflection gives us a rough mode of estimating the quantity of voltaic fluid evolved by the battery.

The Electric Telegraph consists of two or more galvanometers, by means of which telegraphic signals may be transmitted from one railway station to another. The number, order, &c., of the oscillations of the needle, being associated with certain letters and words, enable the operator at one station to communicate messages to the person at the other station.

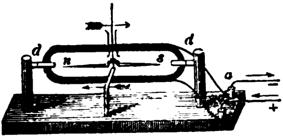

Fig. 84.

But, instead of bending the wire round the needle once, if we bend it twice, thrice, or any number of times, we must obviously increase the deflecting power in the same ratio. This construction is adopted in the galvanometer represented in *fig.* 84.; where *n s* is the needle surrounded by a series of coils of covered silk wire, *a d d.* This instrument has been called the *galvanometer multiplier.*

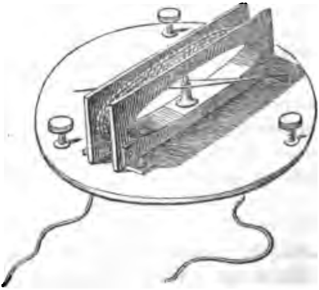

Fig. 85.

Fig. 85. represents a more elegant form of the instrument; where the coil of wire is wound round a wooden frame fixed upon a stand, and provided with binding-screws.

Nobili's galvanometer multiplier, represented in *fig.* 86., consists of an *æstatic needle* (see p. 34.), suspended by a filament of untwisted silk, one of the needles being placed within the conducting coil, the other without it; so that the current of electricity tends to deflect both needles in the same direction, thereby giving a double power to the instrument. The whole of the coil, together with the needle and its thread of suspension, are covered with a glass shade; *a* and *b*, fixed to the binding-screws, are the wires proceeding from the poles of the current, whose power is to be determined by the instrument; the extremities of the wire coil, of course, terminate in these binding-screws.

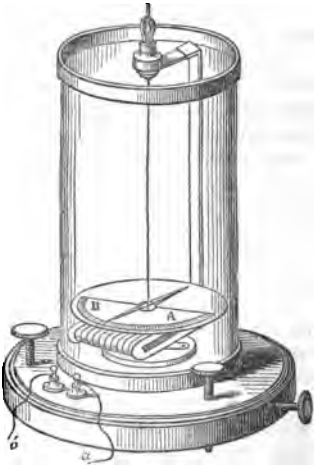

Fig. 86.

ACTION OF ELECTRIC CURRENTS ON EACH OTHER.

Ampère discovered the following laws, according to which electric currents act upon each other:

1. ***Parallel currents attract each other when they flow in the same direction.***

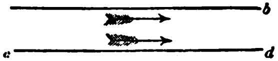

Fig. 87.

Thus the parallel wires, *a b* and *c d*, represented in *fig.* 87., transmitting currents in the same direction, attract each other.

2. ***Parallel currents repel each other when they flow in contrary directions.***

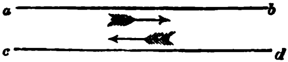

Fig. 88.

Thus the parallel wires, *a b* and *c d*, represented in *fig.* 88., transmitting contrary currents, repel each other.

These laws are perfectly in accordance with the theory of magnetism explained at p. 35.

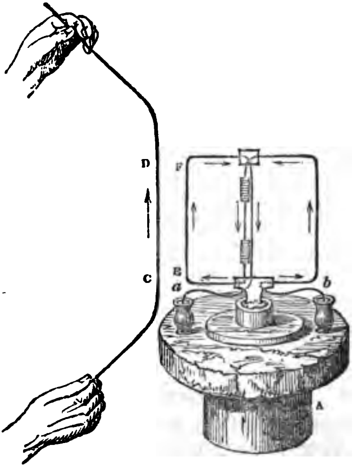

Fig. 89.

In order to establish these laws by experiment, the floating battery represented in *fig.* 89. may be employed. This battery consists of a pair of plates, viz., platinum and amalgamated zinc, fixed to a cork float A, and having its poles in connection with the cups *a* and *b*; the wire frame proceeding from these cups conducts the current as represented by the arrows in the figure; the whole of this floating battery is placed in a vessel containing diluted sulphuric acid, which acts as the exciting fluid. To one of the vertical branches, E F, we present a parallel wire, C D, traversed by a powerful current of electricity; then when the currents flow in the same direction, the wire E F with its floating battery is attracted by the wire C D; and, on the contrary, when the current in the wire C D flows in a contrary direction, the floating battery is repelled.

The same laws hold true with respect to angular currents, or those currents whose directions are inclined to each other; the form of expression in this case being simply, that *currents which are directed to the same point, or which proceed from the same point, attract each other, and* vice versâ, *as before.*

VARIOUS MOTIONS PRODUCED BY THE MUTUAL ACTION OF MAGNETS AND CURRENTS, AND CURRENTS UPON EACH OTHER.

The oscillating electrical spiral, represented in *fig.* 90., affords a beautiful illustration of the attraction of parallel currents. A fine flexible copper spiral wire A, is suspended from the extremity of a conductor D, proceeding from the positive pole of the battery; the lower extremity of this spiral dips slightly into a cup of mercury *a*, in which is placed the extremity of

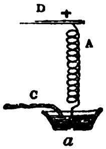

Fig. 90.

the wire C, leading from the negative pole of the battery. When the current is complete, the spiral vibrates longitudinally; for at every contraction the current is broken, and then the weight of the wire causes its extremity to sink again into the mercury, and thus a continuous oscillation is sustained.

It has been shown that *a fixed or closed current exerts a tangential force upon the pole of a magnet which is free to move:* thus let A B, in *fig.* 91., represent the direction of the fixed current, and N the pole of a magnet, free to obey the impulse; then the north pole N is impelled in the tangential direction N *n*, that is to say, in a direction perpendicular to the direction of the current, A B.

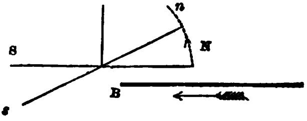

Fig. 91.

In like manner, since action and reaction are equal and contrary, a *pole of a magnet exerts a tangential force on a current which is free to move;* thus the pole N of a fixed magnet (see *fig.* 92.) will impel the free wire A B conducting a current in the tangential direction B *a*.

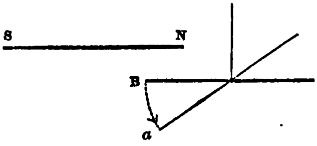

Fig. 92.

These results are generally represented in *fig.* 93., where N represents the north pole of a magnet, C the section of the conductor of a descending electric current perpendicular to the plane of the paper; [illegible] the action of C upon N tends to move it in the direction N *n*, and the reaction of the pole N upon the wire C tends to move it in the contrary direction C *c*. If, therefore, the pole N be free to move round the wire C, the tangential line N *n* will be the direction of the motion; and if the conducting wire C be free to move round the pole N, the tangential line C *c* will be the direction of the motion.

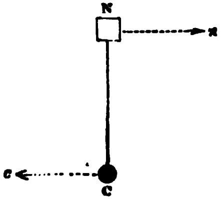

Fig. 93.

The following rotatory motions depend on these principles.

To make the pole of a magnet, N, *revolve round a fixed electric current* C.

This was first effected by Faraday in the following manner:—A small magnet N, is fixed to the lower part of a vessel V, by means of a silk thread; the vessel is filled with mercury nearly to the top of the magnet; C is a conducting wire dipping into the mercury, and Z is another conductor communicating with the mercury at the bottom of the vessel. Now when the electric current is established, by connecting the extremities of the wires, C and Z, with the opposite poles of the battery, the pole N of the magnet revolves round the conducting wire C. The ends of the wires should be amalgamated to ensure metallic contact. If the current is descending, that is, if C be connected with the positive pole of the battery, and if N be a north pole, its motion round the wire will be direct, that is, in the direction of the hands of a watch; and so on *vice versâ*.

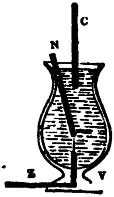

Fig. 94.

To make a moveable wire, A B, *traversed by a current, revolve round the pole,* N, *of a fixed magnet.*

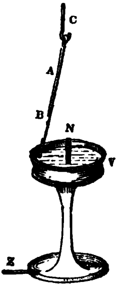

Fig. 95.

Here the wire A B is suspended from the wire C by a loop, and dips into the mercury in the vessel V; when the circuit is established, by connecting the wires, C and Z, with the respective poles of the battery, the conducting wire revolves round the pole, N, of the magnet.

If the current be descending, and N be the north pole of the magnet, the rotation will be direct.

These two rotations may be exhibited in one piece of apparatus, as represented in *fig.* 96., where *m* represents the revolving small magnet, which is best made with a sewing needle; *f p* the revolving wire; *c* the positive pole of the battery; and *z* the negative pole. When the north poles of the magnets are both turned upwards, the rotations take place in the directions of the arrows, as shown in the figure. Reverse the direction of the electric current, and the rotations will be reversed.

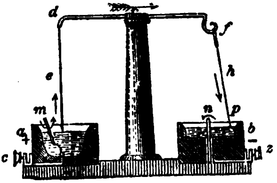

Fig. 96.

Ampère's rotation of a current about the pole of a magnet.

On the two poles, N and S, of a permanent horse-shoe magnet, are placed two cells of copper (*a c c e n* on N, and *e z z a n* on S); *b d*, *b d*, are copper wires attached to cylinders of amalgamated zinc, which dip into the diluted sulphuric acid, filling the cells; these zinc cylinders turn on pivots at *s s*; the zinc cylinders revolve round the respective poles of the magnet in contrary directions, that is, in the directions indicated by the arrows.

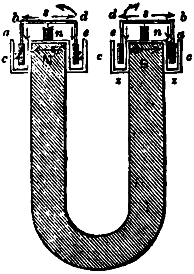

Fig. 97.

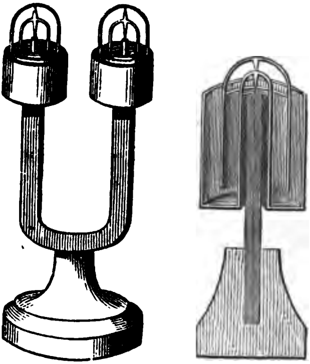

Fig. 98.

Fig. 98. represents a slight modification of the foregoing; here the copper cell turns upon a pivot, as well as the zinc cylinder; and for an obvious reason they revolve in contrary directions.

ELECTRO-DYNAMIC INDUCTION.

FARADAY was the first philosopher who discovered the laws of electro-dynamic induction. He showed that an electric current, or a magnet, is able by induction to develope at a distance electric currents in a conducting wire; in the same way as common electricity electrizes an insulated conductor by induction.

Experiment 1. To show the induction of a current by magnetism; take the coil, represented in *fig.* 81., and place its extremities C and Z, in connection with the respective binding screws of a galvanometer; suddenly insert a strong cylindrical magnet within the coil, and the needle will be instantly deflected, but it will almost immediately return to its original position; suddenly withdraw the magnet, and the needle will be deflected in the opposite direction.

Thus it appears that the induction of the current acts only at the instants of application and withdrawal of the magnet.

This explains the principle on which Clark's magneto-electric machine acts.

Exp. 2. Attach small copper cylinders near to the respective extremities of the wire C and Z; and place a bundle of soft iron rods, (insulated from each other by a coating of shell-lac) into the coil; connect the wires C and Z, with the poles of the battery; hold the copper cylinders in the hands, and suddenly withdraw one of the wires from the pole of the battery, and a pretty powerful electric shock will be felt, and at the same time a spark will be given off from the point of the wire; at the moment of restoring the contact another shock will be felt.

The current produced in these experiments is called a *primary current:* a *secondary current* is produced in the following manner.

Over the coil of wire described in the foregoing experiments, let an exactly similar coil be formed upon it; let *fig.* 99. represent this double coil, where *a* and *b* are the ends of the first or *primary* coil, *c* and *d* the ends of the second or *secondary* coil. Connect the ends *a* and *b* with the poles of a battery, and the ends *c* and *d* with a galvanometer; then the needle will be instantly deflected, showing that a secondary current had been induced in the second coil by the primary current in the first coil; suddenly take away one of the wires from the cup of the galvanometer and the needle will be deflected in the opposite direction. The induced currents only exist for an instant, viz., at the instant of making or of breaking the contact.

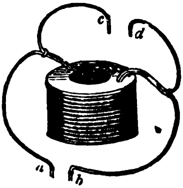

Fig. 99

MAGNETO-ELECTRIC MACHINES.

One of the most simple machines of this kind is represented in *fig.* 100. J J, is a sectional representation of a double induction spiral; *r r*, the wooden hollow roller on which the primary coil of *stout* copper wire, *a a*, is wrapped; *b b*, the secondary coil of fine wire surrounding the first coil; *m*, the bundle of iron wires placed in the hollow

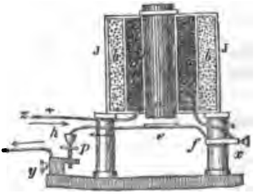

Fig. 100.

axis of the coils, and projecting with its lower pole a little beyond the wooden cylinder; one end *z*, of the wire of the primary coil, is connected with one pole of a constant battery, and the other end *y h f x*, of the wire of the primary coil, with the other pole of the battery; that portion of the conductor *p h e f*, between the two binding screws *y* and *x*, acts as the contact breaker. This *contact breaker* is constructed as follows: it is soldered at *f*, to a flexible plate screwed to the rod proceeding from the binding screw *x*; *e*, is a plate of soft iron, soldered to the conducting wire, exactly under the electro-magnetic rods *m*; at *h*, the conducting wire is bent downwards, and terminates with a hammer, having a platinum point, which rests upon a copper plate or anvil *p*. When the hammer *h*, is in contact with the anvil *p*, the electrical current is complete, and the soft iron wires *m*, become powerfully magnetised by the primary current, the magnet then attracts the plate *e*, and breaks the contact, the rods instantly lose their magnetism, and then the hammer *h*, falls upon the anvil *m*, and thereby again restores the electrical current; and so on. This process goes on with great rapidity, so long as the connection of the wires *z* and *y*, with the poles of the battery is maintained.

Vivid sparks are emitted between the hammer and the anvil, every time the connection is broken or made.

Substances to be subject to the action of the electric current, must be interposed between the binding screws *x* and *y*; thus the thermal, chemical, magnetising, and physiological effects may be observed, at the instant the contact of the hammer with the anvil is broken or destroyed.

But the secondary current is that which should be used for producing the shocks or physiological effects. For this purpose the extremities of the wire forming the secondary coil *b b*, are soldered to small copper cylinders, and these are held in the hands of the person wishing to receive the shocks, one cylinder in each hand, A rapid succession of shocks is felt, for the effect takes place at every time the contact of the hammer with the anvil is broken or renewed.

This machine has been constructed in various forms; sometimes Richie's rotating magnet is used for breaking and renewing the connection of the conducting wire of the primary coil with the poles of the battery.

Faraday's Magneto-electric Machine.

The first machine of this kind was constructed by Faraday, as shown in *fig.* 101. It is thus described by Brand in his Manual of Chemistry.

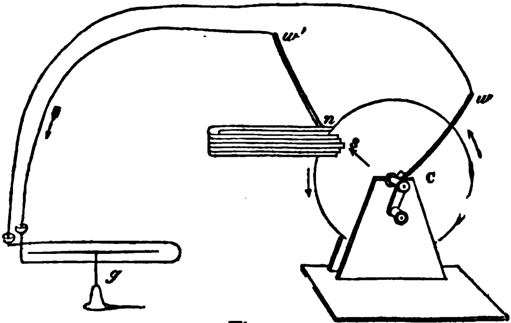

Fig. 101.

c, is a copper plate, so mounted as to admit of revolving on its axis; *n s* are the poles of a powerful horse-shoe magnet, so placed as to admit of the revolution of the plate between them; *w w′* are conducting wires, one of which is retained in metallic contact with the axis, and the other with the rim of the plate, at the point between the poles *n s*. These wires are connected with the galvanometer *g*. When the copper plate is made to revolve from right to left, a current of electricity is produced in the direction of the arrows, and deflects the galvanometer accordingly.

Clark's Magneto-electric Machine.

Pixii first made a machine of this kind, which was successively improved by Saxton and Clark. The arrangement adopted by Clark is thus described by M. Becquérel in his treatise on Electricity.

A (*fig.* 102.) represents a series of six magnetized bars of steel, bent into a horse-shoe form, arranged vertically, and supported by four screws fixed to the board B, two of which are seen at M N (*fig.* 103.) A thick bar of brass C is pierced in its centre by an opening, into which passes a bolt with a nut for the purpose of securing the magnet against the board B. By this arrangement, the magnet may be easily removed without disturbing the rest of the apparatus. D represents the armature of a double cylinder of soft iron G F, which is fixed to a brass screw placed between the poles of the battery A. This piece is set in motion in the manner indicated in *fig.* 103., by means of the wheel E, of an axis of rotation, and an endless cord. On each cylinder is rolled a helix of fine copper wire, coated with silk, and about 800 yards in length. One of the ends of each helix is soldered to the armature; perpendicular to the surface of which, at D, is a brass rod supporting two break-pieces, H.

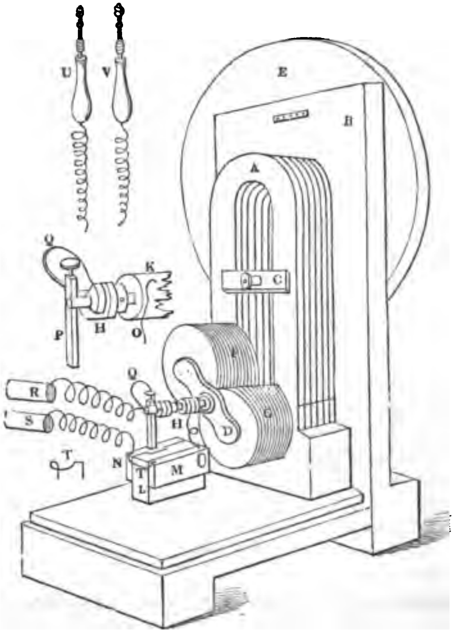

Fig. 102.

K represents a hollow brass cylinder, to which is soldered one of the free ends of the helices, and which is separated from the rod by means of a piece of hard wood resting on it; the other end of the helices is in communication with the rod. O is an iron wire spring to exercise a pressure against the hollow cylinder K, with which it is in metallic contact, by means of a screw fixed in the brass plate M. P represents a square vertical brass rod fitted into the brass plate N. Q is a metal spring exercising a feeble pressure on the break-piece H:

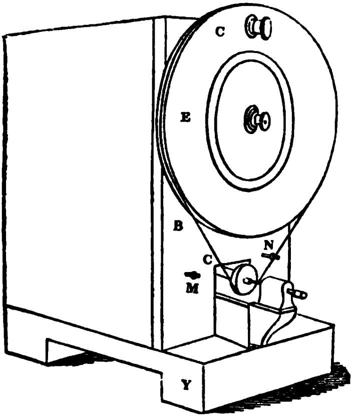

Fig. 103.

it is held in metallic contact by means of a binding screw. T is a copper wire for making communication between the brass plates M N. By means of this arrangement, these various parts D, H, Q, P, N, are in connection with one of the ends, and K and M with the two other ends. It is very evident that, as the spring Q presses gently on the break-piece H, the effects are regular. . . . . . It is very necessary that the break-piece be so arranged that the spring Q shall separate, at the very time when the iron cylinders of the armature are leaving the poles of the magnet. With respect to the iron wire O, it always exercises a gentle pressure against the hollow brass cylinder K. By means of these arrangements a mercury bath, which is always inconvenient, is superseded. When the shock is to be given by this machine, the two copper conductors R S (*fig.* 102.) are taken into the hands, which are moistened with salt water, one of the conductors being in communication with the plate M, and the other with the plate N, in the manner shown in the figure; M and N are then united by the piece T. The shock received by this apparatus as soon as the wheel is turned is very violent. If we desire a current always in the same direction, one break-piece only is placed on. In this case, the circuit is interrupted when the current changes, that is, when each helix quits one branch of the magnet. . . . On placing the two connecting wires R S, between M N, the shock is not so powerful.—U and V (*fig.* 102.) are handles connected witht he conducting wires, and furnished with pieces of sponge, which are employed in the application of electricity for medical purposes. These sponges are moistened with acid or saline solutions. By means of them a succession of the most powerful shocks may be applied where they are needed. . . . To decompose water, Mr. Clark uses the apparatus (*fig.* 104.) arranged in the following manner:—A is an earthen vessel with a brass lid, having a base of hard wood, through which pass two copper wires soldered to platinum wires, and which are connected with M N. Two tubes A, are filled with water, and then placed over the platinum wires, where they are supported by a cork. The two

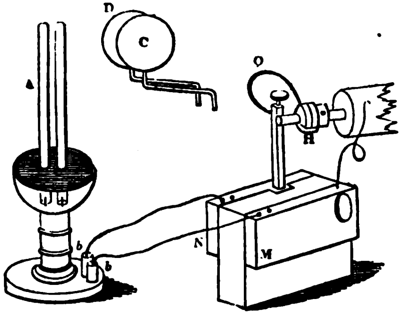

Fig. 104.

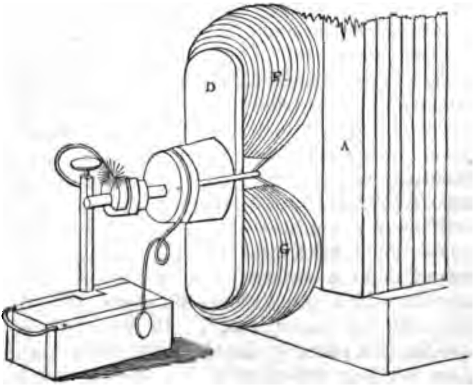

Fig. 105.

plates of platinum C and D, which are connected by copper wires with M and N, are for showing the effects of electro-chemical decompositions. For this purpose, a piece of litmus or turmeric paper, previously moistened with a neutral salt, is placed between the discs. In the place of the two preceding helices and their accessories, which he calls the *intensity armature*, because the current obtained is from electricity of high tension, Mr. Clark employs a quantity armature formed of less powerful cylinders, and with a copper wire, covered with silk, only 45 yards long, the diameter of which is greater. *Fig.* 105. represents the apparatus furnished with this new armature. A is the horse-shoe magnet, D the armature, F and G the two helices. Attention must be paid that the spring quits the break-piece at the moment when the piece is vertical, for then it is that it is in a neutral position relative to the poles of the magnet. To fuse iron wire with bright scintillations, one end of the wire is connected with the end P, and the other end is gently pressed on the rotating armature D. If we wish to obtain sparks of different colours by the employment of different metals, the break piece is taken away, and the piece of copper B (*fig.* 106.) is substituted. In its open part, is introduced a piece of any metallic wire C, gold for example; the extremity of the spring G is also of gold. On making the apparatus rotate, purple coloured sparks are obtained."

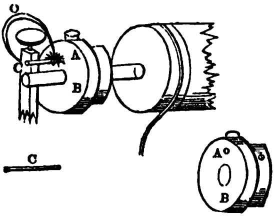

Fig. 106.

THERMO-ELECTRICITY.

The electricity which is developed by heat is called thermo-electricity. When two different metal-rods, such as copper and platinum, or antimony and bismuth, are soldered together, and heated at the part of junction, electricity is generated.

Experiment 1. Twist the end of a copper wire round one end of a platinum wire; place the other extremities in connection with the binding-screws of a galvanometer; heat the twisted extremities with the flame of a spirit; the needle of the galvanometer will be instantly deflected.

Exp. 2. Fix two copper wires into the binding-screws of a galvanometer; heat the free end of one wire with the flame of a spirit-lamp; bring the free end of the other wire into contact with this heated wire; the needle will be instantly deflected, thereby showing the existence of an electric current. It is desirable that the end of the wire, which is to be heated, should terminate with a small plate.

Exp. 3. The simple apparatus, represented in *fig.* 107., exhibits the effects of thermo-electricity in a very striking manner. *a b c d e* is a strip of copper, bent into the form shown in the figure, and rivetted at *e*. A small magnetic needle *n s* is suspended between the plates. Heat the free end *a* of the copper frame with the flame of a spirit-lamp, and the needle will be instantly deflected.

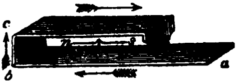

Fig. 107.

Thermo-electric Batteries.

These batteries are formed by soldering together a series of pairs of metal bars, as shown in *fig.* 108., where the dark lines represent the bars of the same kind of metal, and the faint lines those of the other kind of metal. Heat is applied at the junctions, *a a a*, while the junctions, *b b b*, are kept cool.

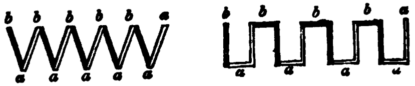

Fig. 108.

The extreme ends *a b*, form the poles of the battery, which may be connected with binding-screws, &c. Bismuth and antimony are the two metals most commonly used in constructing these batteries, when the heat employed is moderate; but if the heat to which the battery is to be exposed is great, platinum and iron should be used.

A thermo-electric battery is sometimes used as a thermometer. *Fig.* 109. represents an apparatus of this kind. *a*, the tin or brass box which contains the thermo-battery s, composed of bismuth and antimony bars, arranged according to the principle explained in connection with *fig.* 108.; *m* and *p* the binding-screws connected with the poles of the battery; wires pass from these binding-screws to the galvanometer; *b* and *c* are the two lids of the box. When heat, in any form, is applied at s, the deflection of the needle indicates

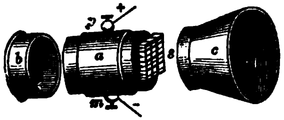

Fig. 109.

the degree of temperature of that heat. This instrument is much used for detecting *very minute* differences of temperature. A good instrument will readily detect, by the deflection of the needle, a difference of temperature of a hundredth part of a degree.

ACTION OF ELECTRO-MAGNETS UPON DIFFERENT BODIES.

All bodies which are capable of being magnetised are called *magnetic* bodies; but Faraday has recently shown that magnetism exerts on all bodies, more or less, a certain peculiar influence, very different from the magnetic; those bodies are called *dia-magnetic*. Thus the flame of a candle undergoes a peculiar change when placed between the poles of a powerful magnet; and light, when made to pass over the poles of a magnet, undergoes a change of polarity; and so on to various other dia-magnetic bodies.

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